US010108652B2

(12) **United States Patent**
Kumarasamy et al.

(10) **Patent No.: US 10,108,652 B2**
(45) **Date of Patent: *Oct. 23, 2018**

(54) **SYSTEMS AND METHODS TO PROCESS BLOCK-LEVEL BACKUP FOR SELECTIVE FILE RESTORATION FOR VIRTUAL MACHINES**

(71) Applicant: **Commvault Systems, Inc.**, Tinton Falls, NJ (US)

(72) Inventors: **Paramasivam Kumarasamy**, Morganville, NJ (US); **Rahul S. Pawar**, Marlboro, NJ (US); **Amit Mitkar**, Neptune, NJ (US); **Satish Chandra Kilaru**, Manalapan, NJ (US)

(73) Assignee: **Commvault Systems, Inc.**, Tinton Falls, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 24 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/197,297**

(22) Filed: **Jun. 29, 2016**

(65) **Prior Publication Data**

US 2016/0306715 A1 Oct. 20, 2016

Related U.S. Application Data

(63) Continuation of application No. 14/098,894, filed on Dec. 6, 2013, now Pat. No. 9,495,404.

(Continued)

(51) **Int. Cl.**
G06F 7/00 (2006.01)
G06F 17/00 (2006.01)

(Continued)

(52) **U.S. Cl.**
CPC ***G06F 17/30345*** (2013.01); ***G06F 9/45558*** (2013.01); ***G06F 11/1469*** (2013.01);

(Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,417,321	A	11/1983	Chang et al.
4,641,274	A	2/1987	Swank

(Continued)

FOREIGN PATENT DOCUMENTS

EP	0259912	A1	3/1988
EP	0405926	A2	1/1991

(Continued)

OTHER PUBLICATIONS

Armstead et al., "Implementation of a Campus-wide Distributed Mass Storage Service: The Dream vs. Reality," IEEE, Sep. 11-14, 1995, pp. 190-199.

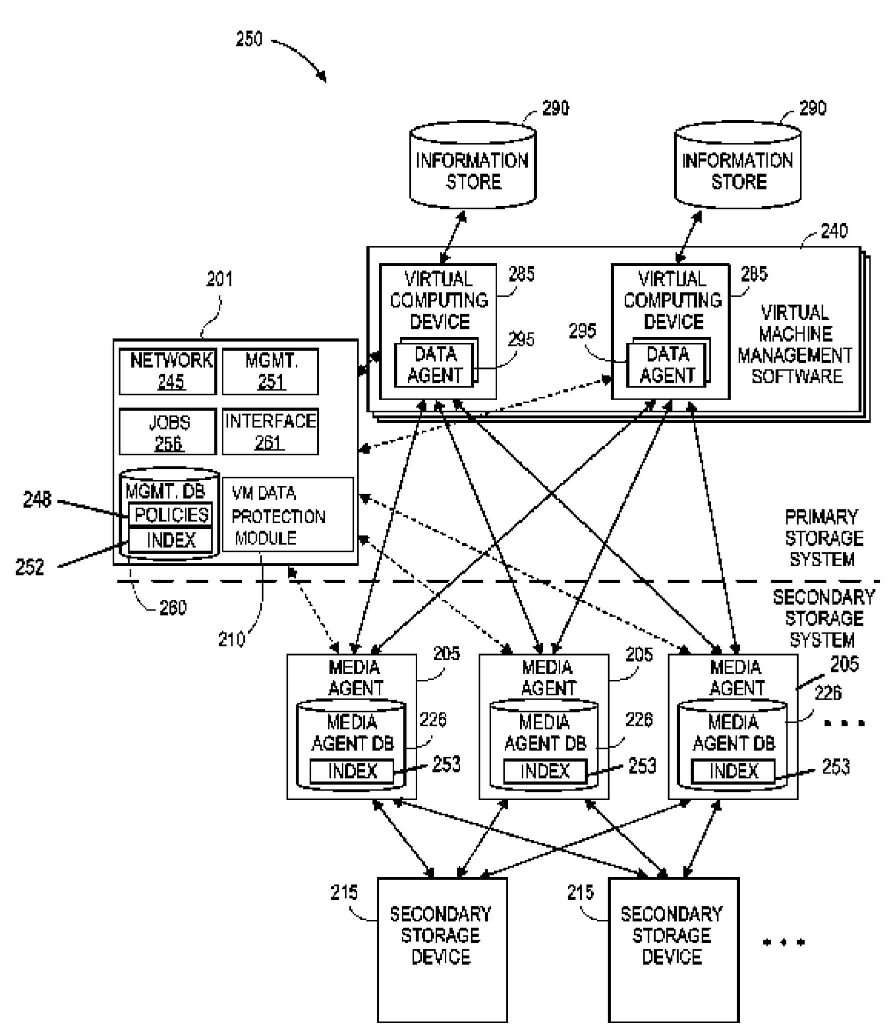
(Continued)

Primary Examiner — Susan Chen
(74) *Attorney, Agent, or Firm* — Knobbe, Martens, Olson & Bear, LLP

(57) **ABSTRACT**

A data storage system protects virtual machines using block-level backup operations and restores the data at a file level. The system accesses the virtual machine file information from the file allocation table of the host system underlying the virtualization layer. A file index associates this virtual machine file information with the related protected blocks in a secondary storage device during the block-level backup. Using the file index, the system can identify the specific blocks in the secondary storage device associated with a selected restore file. As a result, file level granularity for restore operations is possible for virtual machine data protected by block-level backup operations without restoring more than the selected file blocks from the block-level backup data.

16 Claims, 8 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 61/751,456, filed on Jan. 11, 2013.

(51) **Int. Cl.**
G06F 17/30 (2006.01)
G06F 11/14 (2006.01)
G06F 9/455 (2018.01)

(52) **U.S. Cl.**
CPC .. ***G06F 17/30091*** (2013.01); ***G06F 17/30126*** (2013.01); ***G06F 17/30233*** (2013.01); *G06F 11/1458* (2013.01); *G06F 11/1461* (2013.01); *G06F 2009/45583* (2013.01); *G06F 2201/815* (2013.01); *G06F 2201/84* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,654,819 A 3/1987 Stiffler et al.
4,686,620 A 8/1987 Ng
4,995,035 A 2/1991 Cole et al.
5,005,122 A 4/1991 Griffin et al.
5,093,912 A 3/1992 Dong et al.
5,133,065 A 7/1992 Cheffetz et al.
5,193,154 A 3/1993 Kitajima et al.
5,212,772 A 5/1993 Masters
5,226,157 A 7/1993 Nakano et al.
5,239,647 A 8/1993 Anglin et al.
5,241,668 A 8/1993 Eastridge et al.
5,241,670 A 8/1993 Eastridge et al.
5,276,860 A 1/1994 Fortier et al.
5,276,867 A 1/1994 Kenley et al.
5,287,500 A 2/1994 Stoppani, Jr.
5,301,286 A 4/1994 Rajani
5,321,816 A 6/1994 Rogan et al.
5,333,315 A 7/1994 Saether et al.
5,347,653 A 9/1994 Flynn et al.
5,410,700 A 4/1995 Fecteau et al.
5,420,996 A 5/1995 Aoyagi
5,448,724 A 9/1995 Hayashi
5,454,099 A 9/1995 Myers et al.
5,491,810 A 2/1996 Allen
5,495,607 A 2/1996 Pisello et al.
5,504,873 A 4/1996 Martin et al.
5,544,345 A 8/1996 Carpenter et al.
5,544,347 A 8/1996 Yanai et al.
5,559,957 A 9/1996 Balk
5,559,991 A 9/1996 Kanfi
5,619,644 A 4/1997 Crockett et al.
5,638,509 A 6/1997 Dunphy et al.
5,642,496 A 6/1997 Kanfi
5,664,204 A 9/1997 Wang
5,673,381 A 9/1997 Huai et al.
5,699,361 A 12/1997 Ding et al.
5,729,743 A 3/1998 Squibb
5,751,997 A 5/1998 Kullick et al.
5,758,359 A 5/1998 Saxon
5,761,677 A 6/1998 Senator et al.
5,764,972 A 6/1998 Crouse et al.
5,778,395 A 7/1998 Whiting et al.
5,812,398 A 9/1998 Nielsen
5,813,009 A 9/1998 Johnson et al.
5,813,017 A 9/1998 Morris
5,875,478 A 2/1999 Blumenau
5,887,134 A 3/1999 Ebrahim
5,901,327 A 5/1999 Ofek
5,924,102 A 7/1999 Perks
5,950,205 A 9/1999 Aviani, Jr.
5,974,563 A 10/1999 Beeler, Jr.
6,021,415 A 2/2000 Cannon et al.
6,026,414 A 2/2000 Anglin
6,052,735 A 4/2000 Ulrich et al.
6,076,148 A 6/2000 Kedem
6,094,416 A 7/2000 Ying
6,101,585 A 8/2000 Brown et al.
6,131,095 A 10/2000 Low et al.
6,131,190 A 10/2000 Sidwell
6,148,412 A 11/2000 Cannon et al.
6,154,787 A 11/2000 Urevig et al.
6,161,111 A 12/2000 Mutalik et al.
6,167,402 A 12/2000 Yeager
6,212,512 B1 4/2001 Barney et al.
6,260,069 B1 7/2001 Anglin
6,269,431 B1 7/2001 Dunham
6,275,953 B1 8/2001 Vahalia et al.
6,301,592 B1 10/2001 Aoyama et al.
6,324,581 B1 11/2001 Xu et al.
6,328,766 B1 12/2001 Long
6,330,570 B1 12/2001 Crighton
6,330,642 B1 12/2001 Carteau
6,343,324 B1 1/2002 Hubis et al.
RE37,601 E 3/2002 Eastridge et al.
6,356,801 B1 3/2002 Goodman et al.
6,389,432 B1 5/2002 Pothapragada et al.
6,418,478 B1 7/2002 Ignatius et al.
6,421,711 B1 7/2002 Blumenau et al.
6,487,561 B1 11/2002 Ofek et al.
6,519,679 B2 2/2003 Devireddy et al.
6,538,669 B1 3/2003 Lagueux, Jr.
6,542,972 B2 4/2003 Ignatius et al.
6,564,228 B1 5/2003 O'Connor
6,581,076 B1 6/2003 Ching et al.
6,658,436 B2 12/2003 Oshinsky et al.
6,658,526 B2 12/2003 Nguyen et al.
6,721,767 B2 4/2004 De Meno et al.
6,760,723 B2 7/2004 Oshinsky et al.
7,003,641 B2 2/2006 Prahlad et al.
7,035,880 B1 4/2006 Crescenti et al.
7,076,270 B2 7/2006 Jaggers et al.
7,107,298 B2 9/2006 Prahlad et al.
7,130,970 B2 10/2006 Devassy et al.
7,162,496 B2 1/2007 Amarendran et al.
7,174,433 B2 2/2007 Kottomtharayil et al.
7,219,162 B2 5/2007 Donker et al.
7,246,207 B2 7/2007 Kottomtharayil
7,315,923 B2 1/2008 Retnamma et al.
7,324,543 B2 1/2008 Wassew et al.
7,343,356 B2 3/2008 Prahlad et al.
7,343,453 B2 3/2008 Prahlad et al.
7,346,751 B2 3/2008 Prahlad et al.
7,386,744 B2 6/2008 Barr et al.
7,389,311 B1 6/2008 Crescenti et al.
7,395,282 B1 7/2008 Crescenti
7,440,982 B2 10/2008 Lu et al.
7,448,079 B2 11/2008 Tremain
7,454,569 B2 11/2008 Kavuri et al.
7,475,282 B2 1/2009 Tormasov et al.
7,490,207 B2 2/2009 Amarendran et al.
7,500,053 B1 3/2009 Kavuri et al.
7,502,820 B2 3/2009 Manders et al.
7,529,782 B2 5/2009 Prahlad et al.
7,536,291 B1 5/2009 Vijayan Retnamma et al.
7,543,125 B2 6/2009 Gokhale
7,546,324 B2 6/2009 Prahlad et al.
7,603,386 B2 10/2009 Amarendran et al.
7,606,844 B2 10/2009 Kottomtharayil
7,613,752 B2 11/2009 Prahlad et al.
7,617,253 B2 11/2009 Prahlad et al.
7,617,262 B2 11/2009 Prahlad et al.
7,620,710 B2 11/2009 Kottomtharayil et al.
7,631,351 B2 12/2009 Erofeev
7,636,743 B2 12/2009 Erofeev
7,640,406 B1 12/2009 Hagerstrom et al.
7,651,593 B2 1/2010 Prahlad et al.
7,657,550 B2 2/2010 Prahlad et al.
7,660,807 B2 2/2010 Prahlad et al.
7,661,028 B2 2/2010 Erofeev
7,668,884 B2 2/2010 Prahlad et al.
7,685,177 B1 3/2010 Hagerstrom et al.
7,694,070 B2 4/2010 Mogi et al.
7,721,138 B1 5/2010 Lyadvinsky et al.
7,730,035 B2 6/2010 Berger et al.
7,747,579 B2 6/2010 Prahlad et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,756,835	B2	7/2010	Pugh
7,756,964	B2	7/2010	Madison, Jr. et al.
7,765,167	B2	7/2010	Prahlad et al.
7,778,984	B2	8/2010	Zhang et al.
7,792,789	B2	9/2010	Prahlad et al.
7,801,864	B2	9/2010	Prahlad et al.
7,809,914	B2	10/2010	Kottomtharayil et al.
7,822,967	B2	10/2010	Fung
7,840,537	B2	11/2010	Gokhale
7,882,077	B2	2/2011	Gokhale et al.
7,899,788	B2	3/2011	Chandhok et al.
7,937,421	B2	5/2011	Mikesell et al.
8,001,277	B2	8/2011	Mega et al.
8,037,028	B2	10/2011	Prahlad et al.
8,037,032	B2	10/2011	Pershin et al.
8,046,550	B2	10/2011	Feathergill
8,060,476	B1	11/2011	Afonso et al.
8,069,271	B2	11/2011	Brunet et al.
8,099,391	B1	1/2012	Monckton
8,117,492	B1	2/2012	Searls et al.
8,135,930	B1	3/2012	Mattox et al.
8,140,786	B2	3/2012	Bunte
8,170,995	B2	5/2012	Prahlad et al.
8,185,893	B2	5/2012	Hyser et al.
8,200,637	B1	6/2012	Stringham
8,219,524	B2	7/2012	Gokhale
8,219,769	B1	7/2012	Wilk
8,229,954	B2	7/2012	Kottomtharayil et al.
8,285,681	B2	10/2012	Prahlad et al.
8,307,177	B2	11/2012	Prahlad et al.
8,307,187	B2	11/2012	Chawla et al.
8,315,992	B1	11/2012	Gipp et al.
8,364,652	B2	1/2013	Vijayan et al.
8,370,542	B2	2/2013	Lu et al.
8,396,838	B2	3/2013	Brockway
8,407,190	B2 *	3/2013	Prahlad G06F 17/302 707/692
8,433,679	B2	4/2013	Crescenti
8,434,131	B2	4/2013	Varadharajan
8,453,145	B1	5/2013	Naik
8,473,594	B2	6/2013	Astete et al.
8,489,676	B1	7/2013	Chaplin et al.
8,560,788	B1	10/2013	Sreedharan et al.
8,578,120	B2	11/2013	Attarde et al.
8,620,870	B2	12/2013	Dwarampudi et al.
8,667,171	B2	3/2014	Guo et al.
8,799,431	B2	8/2014	Pabari
8,831,202	B1	9/2014	Abidogun et al.
8,850,146	B1	9/2014	Majumdar
8,904,081	B1	12/2014	Kulkarni
8,930,543	B2	1/2015	Ashok et al.
8,938,481	B2 *	1/2015	Kumarasamy G06F 17/30575 707/679
9,020,895	B1	4/2015	Rajashekar
9,026,498	B2 *	5/2015	Kumarasamy G06F 17/30079 707/652
9,098,457	B2	8/2015	Towstopiat et al.
9,124,633	B1	9/2015	Eizadi et al.
9,223,597	B2	12/2015	Deshpande et al.
9,239,762	B1	1/2016	Gunda et al.
9,280,378	B2	3/2016	Shah
9,286,086	B2	3/2016	Deshpande et al.
9,286,110	B2	3/2016	Mitkar et al.
9,298,715	B2	3/2016	Kumarasamy et al.
9,311,121	B2	4/2016	Deshpande et al.
9,311,248	B2	4/2016	Wagner
9,397,944	B1	7/2016	Hobbs et al.
9,405,763	B2 *	8/2016	Prahlad G06F 11/1453
9,417,968	B2	8/2016	Dornemann et al.
9,436,555	B2	9/2016	Dornemann et al.
9,451,023	B2	9/2016	Sancheti
9,461,881	B2	10/2016	Kumarasamy
9,477,683	B2	10/2016	Ghosh
9,489,244	B2	11/2016	Mitkar et al.
9,495,404	B2 *	11/2016	Kumarasamy G06F 11/1469
9,575,991	B2	2/2017	Ghosh
9,594,636	B2	3/2017	Mortensen et al.
9,632,882	B2 *	4/2017	Kumarasamy G06F 11/1489
9,652,283	B2	5/2017	Mitkar et al.
9,684,535	B2	6/2017	Deshpande et al.
9,703,584	B2	7/2017	Kottomtharayil et al.
9,710,465	B2	7/2017	Dornemann et al.
9,740,702	B2	8/2017	Pawar et al.
9,766,825	B2 *	9/2017	Bhagi G06F 3/0619
9,766,989	B2	9/2017	Mitkar et al.
9,823,977	B2	11/2017	Dornemann et al.
9,852,026	B2	12/2017	Mitkar et al.
2002/0069369	A1	6/2002	Tremain
2002/0095609	A1	7/2002	Tokunaga
2002/0194511	A1	12/2002	Swoboda
2003/0126494	A1	7/2003	Strasser
2003/0204597	A1	10/2003	Arakawa et al.
2005/0060356	A1	3/2005	Saika
2005/0198303	A1	9/2005	Knauerhase et al.
2005/0216788	A1	9/2005	Mani-Meitav et al.
2006/0058994	A1	3/2006	Ravi et al.
2006/0184935	A1	8/2006	Abels et al.
2006/0195715	A1	8/2006	Herington
2006/0224846	A1	10/2006	Amarendran et al.
2006/0225065	A1	10/2006	Chandhok et al.
2006/0230136	A1	10/2006	Ma
2007/0198802	A1	8/2007	Kavuri
2007/0203938	A1	8/2007	Prahlad et al.
2007/0208918	A1	9/2007	Harbin et al.
2007/0220319	A1	9/2007	Desai et al.
2007/0234302	A1	10/2007	Suzuki et al.
2007/0239804	A1	10/2007	Armstrong et al.
2007/0266056	A1	11/2007	Stacey et al.
2008/0059704	A1	3/2008	Kavuri
2008/0091655	A1	4/2008	Gokhale
2008/0195639	A1	8/2008	Freeman et al.
2008/0228771	A1	9/2008	Prahlad et al.
2008/0229037	A1	9/2008	Bunte
2008/0243855	A1	10/2008	Prahlad
2008/0243947	A1	10/2008	Kaneda
2008/0250407	A1	10/2008	Dadhia et al.
2008/0270564	A1	10/2008	Rangegowda et al.
2008/0282253	A1	11/2008	Huizenga
2008/0320319	A1	12/2008	Muller
2009/0006733	A1	1/2009	Gold et al.
2009/0144416	A1	6/2009	Chatley et al.
2009/0210427	A1	8/2009	Eidler et al.
2009/0228669	A1	9/2009	Siesarev et al.
2009/0240904	A1	9/2009	Austruy et al.
2009/0248762	A1	10/2009	Prahlad et al.
2009/0249005	A1	10/2009	Bender et al.
2009/0287665	A1	11/2009	Prahlad
2009/0300057	A1	12/2009	Friedman
2009/0307166	A1	12/2009	Routray et al.
2009/0313260	A1	12/2009	Mimatsu
2009/0319534	A1	12/2009	Gokhale
2009/0319585	A1	12/2009	Gokhale
2009/0320029	A1	12/2009	Kottomtharayil
2010/0011178	A1	1/2010	Feathergill
2010/0049929	A1	2/2010	Nagarkar et al.
2010/0070466	A1	3/2010	Prahlad et al.
2010/0070474	A1 *	3/2010	Lad G06F 3/0605 707/624
2010/0070725	A1	3/2010	Prahlad et al.
2010/0030984	A1	4/2010	Erickson
2010/0082672	A1	4/2010	Kottomtharayil
2010/0107158	A1	4/2010	Chen et al.
2010/0107172	A1	4/2010	Calinescu et al.
2010/0186014	A1	7/2010	Vaghani et al.
2010/0228913	A1	9/2010	Czezatke et al.
2010/0242096	A1	9/2010	Varadharajan et al.
2010/0257523	A1	10/2010	Frank
2010/0262586	A1	10/2010	Rosikiewicz et al.
2010/0262794	A1	10/2010	De Beer et al.
2010/0299309	A1	11/2010	Maki et al.
2010/0306173	A1	12/2010	Frank
2010/0306486	A1	12/2010	Balasubramanian et al.
2010/0325727	A1	12/2010	Neystad et al.
2010/0332401	A1	12/2010	Prahlad

(56) **References Cited**

U.S. PATENT DOCUMENTS

2010/0332454 A1* 12/2010 Prahlad G06F 17/30082 707/654
2010/0332456 A1 12/2010 Prahlad et al.
2010/0332479 A1 12/2010 Prahlad
2010/0332629 A1 12/2010 Cotugno et al.
2010/0332818 A1 12/2010 Prahlad
2010/0333100 A1 12/2010 Miyazaki et al.
2010/0333116 A1 12/2010 Prahlad
2011/0016467 A1 1/2011 Kane
2011/0022811 A1 1/2011 Kirihata et al.
2011/0047541 A1 2/2011 Yamaguchi et al.
2011/0061045 A1 3/2011 Phillips
2011/0087632 A1 4/2011 Subramanian et al.
2011/0161299 A1 6/2011 Prahlad
2011/0191559 A1 8/2011 Li et al.
2011/0202734 A1 9/2011 Dhakras et al.
2011/0213754 A1 9/2011 Bindal
2011/0225277 A1 9/2011 Freimuth et al.
2011/0239013 A1 9/2011 Muller
2011/0252208 A1 10/2011 Ali et al.
2012/0017043 A1 1/2012 Aizman et al.
2012/0017114 A1 1/2012 Timashev et al.
2012/0072685 A1 3/2012 Otani
2012/0079221 A1 3/2012 Sivasubramanian et al.
2012/0084262 A1 4/2012 Dwarampudi et al.
2012/0110328 A1 5/2012 Pate et al.
2012/0131295 A1 5/2012 Nakajima
2012/0131578 A1 5/2012 Ciano et al.
2012/0136832 A1 5/2012 Sadhwani
2012/0150818 A1 6/2012 Vijayan Retnamma et al.
2012/0150826 A1 6/2012 Vijayan Retnamma et al.
2012/0151084 A1 6/2012 Stathopoulos et al.
2012/0167083 A1 6/2012 Suit
2012/0221843 A1 8/2012 Bak et al.
2012/0254364 A1 10/2012 Vijayan
2012/0278799 A1 11/2012 Starks et al.
2012/0324183 A1 12/2012 Chiruvolu et al.
2012/0331248 A1 12/2012 Kono et al.
2013/0024722 A1 1/2013 Kotagiri
2013/0042234 A1 2/2013 Deluca et al.
2013/0061014 A1 3/2013 Prahlad et al.
2013/0080841 A1 3/2013 Reddy et al.
2013/0117744 A1 5/2013 Klein et al.
2013/0173771 A1 7/2013 Ditto et al.
2013/0204849 A1* 8/2013 Chacko G06F 3/0604 707/692
2013/0227558 A1 8/2013 Du et al.
2013/0232215 A1 9/2013 Gupta et al.
2013/0238562 A1 9/2013 Kumarasamy
2013/0262390 A1 10/2013 Kumarasamy et al.
2013/0262638 A1 10/2013 Kumarasamy et al.
2013/0262801 A1 10/2013 Sancheti et al.
2013/0268931 A1 10/2013 O'Hare et al.
2013/0290267 A1 10/2013 Dwarampudi et al.
2013/0326260 A1 12/2013 Wei et al.
2014/0006858 A1 1/2014 Heitman et al.
2014/0007097 A1 1/2014 Chin et al.
2014/0007181 A1 1/2014 Sarin et al.
2014/0095816 A1 4/2014 Hsu et al.
2014/0136803 A1 5/2014 Qin
2014/0181038 A1 6/2014 Pawar et al.
2014/0181044 A1 6/2014 Pawar et al.
2014/0181045 A1 6/2014 Pawar et al.
2014/0181046 A1 6/2014 Pawar et al.
2014/0188803 A1 7/2014 James et al.
2014/0196038 A1 7/2014 Kottomtharayil et al.
2014/0196039 A1 7/2014 Kottomtharayil et al.
2014/0196056 A1 7/2014 Kottomtharayil et al.
2014/0201151 A1 7/2014 Kumarasamy et al.
2014/0201152 A1 7/2014 Kumarasamy et al.
2014/0201157 A1 7/2014 Pawar et al.
2014/0201162 A1 7/2014 Kumarasamy et al.
2014/0237537 A1 8/2014 Manmohan et al.
2014/0278530 A1 9/2014 Bruce et al.
2014/0282514 A1 9/2014 Carson et al.
2014/0330874 A1 11/2014 Novak et al.
2014/0337295 A1 11/2014 Haselton et al.
2014/0372384 A1 12/2014 Long et al.
2015/0074060 A1 3/2015 Varadharajan et al.
2015/0074536 A1 3/2015 Varadharajan et al.
2015/0120928 A1 4/2015 Gummaraju et al.
2015/0121122 A1 4/2015 Towstopiat et al.
2015/0134607 A1 5/2015 Magdon-Ismail et al.
2015/0160884 A1 6/2015 Scales et al.
2015/0161015 A1 6/2015 Kumarasamy et al.
2015/0163172 A1 6/2015 Mudigonda et al.
2015/0227438 A1 8/2015 Jaquette
2015/0317216 A1 11/2015 Hsu et al.
2015/0347430 A1 12/2015 Ghosh
2015/0363413 A1 12/2015 Ghosh
2015/0370652 A1 12/2015 He et al.
2015/0378758 A1 12/2015 Duggan et al.
2015/0378833 A1 12/2015 Misra et al.
2015/0378849 A1 12/2015 Liu et al.
2016/0019317 A1 1/2016 Pawar et al.
2016/0070623 A1 3/2016 Derk
2016/0132400 A1 5/2016 Pawar et al.
2016/0147607 A1 5/2016 Dornemann et al.
2016/0154709 A1 6/2016 Mitkar et al.
2016/0170844 A1 6/2016 Long et al.
2016/0306558 A1 10/2016 Varadharajan et al.
2016/0306587 A1 10/2016 Dornemann et al.
2016/0306642 A1 10/2016 Kottomtharayil
2016/0306706 A1 10/2016 Pawar et al.
2017/0109087 A1 4/2017 Dornemann
2017/0168903 A1 6/2017 Dornemann et al.
2017/0199756 A1 7/2017 Deshpande et al.
2017/0249220 A1 8/2017 Kumarasamy et al.
2017/0277686 A1 9/2017 Dornemann et al.

FOREIGN PATENT DOCUMENTS

EP 0467546 A2 1/1992
EP 0541281 5/1993
EP 0774715 A1 5/1997
EP 0809184 A1 11/1997
EP 0817040 A2 1/1998
EP 0899662 A1 3/1999
EP 0981090 A1 2/2000
WO WO 95/13580 5/1995
WO WO 99/12098 3/1999
WO WO 2006/052872 5/2006

OTHER PUBLICATIONS

Arneson, "Mass Storage Archiving in Network Environments," Digest of Papers, Ninth IEEE Symposium on Mass Storage Systems, Oct. 31, 1988-Nov. 3, 1988, pp. 45-50, Monterey, CA.

Brandon, J., "Virtualization Shakes Up Backup Strategy," <http://www.computerworld.com>, Feb. 21, 2008, 3 pages.

Cabrera et al., "ADSM: A Multi-Platform, Scalable, Backup and Archive Mass Storage System," Digest of Papers, Compcon '95, Proceedings of the 40th IEEE Computer Society International Conference, Mar. 5, 1995-Mar. 9, 1995, pp. 420-427, San Francisco, CA.

Celesti, et al., "Improving Virtual Machine Migration in Federated Cloud Environments", 2010, pp. 61-67.

Chiappetta, Marco, "ESA Enthusiast System Architecture," <http://hothardware.com/articles/NVIDIA-ESA-Enthusiast-System-Architecture/>, Nov. 5, 2007, 2 pages.

CommVault Systems, Inc., "A CommVault White Paper: VMware Consolidated Backup (VCB) Certification Information Kit," 2007, 23 pages.

CommVault Systems, Inc., "CommVault Solutions—VMware," <http://www.commvault.com/solutions/vmware/>, accessed Apr. 30, 2014, 1 page.

CommVault Systems, Inc., "Enhanced Protection and Manageability of Virtual Servers," Partner Solution Brief, 2008, 6 pages.

Cully, et al., "Remus: High Availability via Asynchronous Virtual Machine Replication", 2008, pp. 161-174.

(56) **References Cited**

OTHER PUBLICATIONS

Data Protection for Large Vmware and Vblock Environments Using EMC Avamar Applied Technology, Nov. 2010, EMC Corporation, 26 pages.
Davis, D., "3 VMware Consolidated Backup (VCB) Utilities You Should Know," Petri IT Knowledgebase, <http://www.petri.co.il/vmware-consolidated-backup-utilities.htm>, Nov. 16, 2007, 3 pages.
Davis, D., "Understanding VMware VMX Configuration Files," Petri IT Knowledgebase, <http://www.petri.co.il/virtual_vmware_vmx_configuration_files.htm>, Nov. 16, 2007, 3 pages.
Davis, D., "VMware Server & Workstation Disk Files Explained," Petri IT Knowledgebase, <http://www.petri.co.il/virtual_vmware_files_explained.htm>, May 3, 2008, 3 pages.
Davis, D., "VMware Versions Compared," Petri IT Knowledgebase, <http://www.petri.co.il/virtual_vmware_versions_compared.htm>, Nov. 16, 2007, 3 pages.
Deng, et al., "Fast Saving and Restoring Virtual Machines with Page Compression", 2011, pp. 150-157.
Eitel, "Backup and Storage Management in Distributed Heterogeneous Environments," IEEE, Jun. 12-16, 1994, pp. 124-126.
Gait, "The Optical File Cabinet: A Random-Access File System for Write-Once Optical Disks," IEEE Computer, vol. 21, No. 6, pp. 11-22 (Jun. 1988) (see in particular figure 5 in p. 15 and recitation in claim 5).
Gupta, et al., "GPFS-SNC: An enterprise storage framework for virtual-machine clouds", 2011, pp. 1-10.
Hirofuchi, et al., "Enabling Instantaneous Relocation of Virtual Machines with a Lightweight VMM Extension", 2010, pp. 73-83.
Hu, et al., "Virtual Machine based Hot-spare Fault-tolerant System", 2009, pp. 429-432.
Huff, KL, "Data Set Usage Sequence Number," IBM Technical Disclosure Bulletin, vol. 24, No. 5, Oct. 1981 New York, US, pp. 2404-2406.
Jander, M., "Launching Storage-Area Net," Data Communications, US, McGraw Hill, NY, vol. 27, No. 4 (Mar. 21, 1998), pp. 64-72.
Liang, et al., "A virtual disk environment for providing file system recovery", 2006, pp. 589-599.
Mao, et al., "Read-Performance Optimization for Deduplication-Based Storage Systems in the Cloud", 2014, pp. 1-22.
Microsoft Corporation, "How NTFS Works," Windows Server TechCenter, <http://technet2.mircrosoft.com/windowsserver/en/library/8cc5891d-bf8e-4164-862d-dac5418c5948 . . . >, updated Mar. 28, 2003, internet accessed Mar. 26, 2008, 26 pages.
Migrate a Virtual Machine with Storage vMotion in the vSphere Client. http://pubs.vmware.com/vsphere-51/advanced/print/jsp?topic=/com.vmware.vsphere.vcent . . . Retrieved Aug. 12, 2014; 2 pages.
Reingold, B. et al., "Cloud Computing: The Intersection of Massive Scalability, Data Security and Privacy (Part I)," LegalWorks, a Thomson Business, Jun. 2009, 5 pages.
Reingold, B. et al., "Cloud Computing: Industry and Government Developments (Part II)," LegalWorks, Sep. 2009, 5 pages.
Reingold, B. et al., "Cloud Computing: Whose Law Governs the Cloud? (Part III)," Legal Works, Jan.-Feb. 2010, 6 pages.
Rosenblum et al., "The Design and Implementation of a Log-Structured File System," Operating Systems Review SIGOPS, vol. 25, No. 5, New York, US, pp. 1-15 (May 1991).
Sanbarrow.com, "Disktype-table," <http://sanbarrow.com/vmdk/disktypes.html>, internet accessed on Apr. 30, 2014, 4 pages.
Sanbarrow.com, "Files Used by a VM," <http://sanbarrow.com/vmx/vmx-files-used-by-a-vm.html>, internet accessed on Apr. 30, 2014, 1 page.
Sanbarrow.com, "Monolithic Versus Split Disks," <http://sanbarrow.com/vmdk/monolithicversussplit.html>, internet accessed on Jul. 14, 2008, 2 pages.
Travostino, et al., "Seamless live migration of virtual machines over the MAN/WAN", 2006, pp. 901-907.
Vaghani, "Virtual Machine File System", 2010, pp. 57-70.
VMware, Inc., "VMware Solution Exchange (VSX)" <http://www.vmware.com/appliances/learn/ovf.html>, 2014, 3 pages.
VMware, Inc., "OVF, Open Virtual Machine Format Specification, version 0.9," White Paper, <http://www.vmware.com>, Sep. 7, 2007, 50 pages.
VMware, Inc., "The Open Virtual Machine Format Whitepaper for OVF Specification, version 0.9," White Paper, <http://www.vmware.com>, 2007, 16 pages.
VMware, Inc., "Understanding VMware Consolidated Backup," White Paper, <http://www.vmware.com>, accessed Apr. 30, 2014, 11 pages.
VMware, Inc., "Using VMware Infrastructure for Backup and Restore," Best Practices, <http://www.vmware.com>, accessed Apr. 30, 2014, 20 pages.
VMware, Inc., "Virtual Disk API Programming Guide," <http://www.vmware.com>, Revision 20080411, 2008, 44 pages.
VMware, Inc., "Virtual Disk Format 1.1," VMware Technical Note, <http://www.vmware.com>, Revision 20071113, Version 1.1, 2007, 18 pages.
VMware, Inc., "Virtualized iSCSI SANS: Flexible, Scalable Enterprise Storage for Virtual Infrastructures," White Paper, <http://www.vmware.com>, Mar. 2008, 13 pages.
VMware, Inc., "Virtual Machine Backup Guide, ESX Server 3.5, ESX Server 3i version 3.5, VirtualCenter 2.5," <http://www.vmware.com>, updated Feb. 21, 2008, 78 pages.
VMware, Inc., "Virtual Machine Backup Guide, ESX Server 3.0.1 and VirtualCenter 2.0.1," <http://www.vmware.com>, updated Nov. 21, 2007, 74 pages.
VMware, Inc., "VMware Consolidated Backup," Product Datasheet, <http://www.vmware.com>, 2009, 2 pages.
VMware, Inc "VMware Consolidated Backup, Improvements in Version 3.5," Information Guide, <http://www.vmware.com>, accessed Apr. 30, 2014, 11 pages.
VMware, Inc., "VMware ESX 3.5," Product Datasheet, <http://www.vmware.com>, 2008, 4 pages.
VMware, Inc., "VMware GSX Server 3.2, Disk Types: Virtual and Physical," <http://www.vmware.com/support/gsx3/doc/disks_types_gsx.html>, 2008, 2 pages.
VMware, Inc., "VMware OVF Tool," Technical Note, <http://www.vmware.com>, 2007, 4 pages.
VMware, Inc., "VMware Workstation 5.0, Snapshots in a Process Tree," <http://www.vmware.com/support/ws5/doc/ws_preserve_sshot_tree.html>, accessed Apr. 30, 2014, 1 page.
VMware, Inc., "VMware Workstation 5.0, Snapshots in a Linear Process," <http:www.vmware.com/support/ws5/doc/ws_preserve_sshot_linear.html>, internet accessed on 2014, 1 page.
VMware, Inc., "VMware Workstation 5.5, What Files Make Up a Virtual Machine?" <http://www.vmware.com/support/ws55/doc/ws_learning_files_in_a_vm.html>, 2014, 2 pages.
VMware Storage VMotion—Non-Disruptive Live Migration for Virtual Machine Storage Disk Files. Copyright 2009 VMware, Inc.; 2 pages.
vSphere Storage vMotion: Storage Management & Virtual Machine Migration. http://www.vmware.com/products /vsphere/features/storage-vmotion Retrieved Aug. 12, 2014; 6 pages.
Wikipedia, "Cloud computing," <http://en.wikipedia.org/wiki/Cloud—computing>, 2009, 11 pages.
Wikipedia, "Cluster (file system)," <http://en.wikipedia.org/wiki/Cluster_%28file_system%29>, Sep. 2, 2008, 1 page.
Wikipedia, "Cylinder-head-sector," <http://en.wikipedia.org/wiki/Cylinder-head-sector>, Jan. 4, 2009, 6 pages.
Wikipedia, "File Allocation Table," <http://en.wikipedia.org/wiki/File_Allocation_Table>, Dec. 3, 2008, 12 pages.
Wikipedia, "Logical Disk Manager," <http://en.wikipedia.org/wiki/Logical_Disk_Manager>, Nov. 16, 2007, 3 pages.
Wikipedia, "Logical Volume Management," <http://en.wikipedia.org/wiki/Logical_volume_management>, Oct. 27, 2008, 3 pages.
Wikipedia, "Storage Area Network," <http://en.wikipedia.org/wiki/Storage_area_network>, Dec. 5, 2008, 5 pages.
Wikipedia, "Virtualization," <http://en.wikipedia.org/wiki/Virtualization>, Apr. 29, 2014, 7 pages.
Wood, et al., "Disaster Recovery as a Cloud Service: Economic Benefits & Deployment Challenges", 2010, pp. 1-7.

(56) **References Cited**

OTHER PUBLICATIONS

Zhao, et al., "Adaptive Distributed Load Balancing Algorithm based on Live Migration of Virtual Machines in Cloud", 2009, pp. 170-175.
International Search Report and Written Opinion for PCT/US2011/054374, dated May 2, 2012, 7 pages.
International Preliminary Report on Patentability and Written Opinion for PCT/US2011/054374, dated Apr. 2, 2013, 9 pages.
Chan, et al., "An Approach to High Availability for Cloud Servers with Snapshot Mechanism," 2012, pp. 1-6.
Chen et al., "When Virtual Is Better Than Real", IEEE 2001, pp. 133-138.
Granger, et al., "Survivable Storage Systems", 2001, pp. 184-195.
Haselhorst, et al., "Efficient Storage Synchronization for Live Migration in Cloud Infrastructures", 2011, pp. 511-518.
Hirofuchio, Takahiro et al., "A live storage migration mechanism over wan and its performance evaluation," 2009, pp. 67-74.
Hu, Wenjin et al., "A Quantitative Study of Virtual Machine Live Migration," 2013, pp. 1-10.
Ibrahim, Shadi et al., "CLOUDLET: Towards MapReduce Implementation on Virtual Machines," 2009, pp. 65-66.
Ismail et al., Architecture of Scalable Backup Service for Private Cloud, IEEE 2013, pp. 174-179.
Jo, Changyeon, et al., "Efficient Live Migration of Virtual Machines Using Shared Storage", 2013, pp. 1-10.
Kuo et al.,"A Hybrid Cloud Storage Architecture for Service Operational High Availability", 2013, pp. 487-492.
Nance et al., "Virtual Machine Introspection: Observation or Interference?", 2008 IEEE.
Ng, Chun-Ho et al., "Live Deduplication Storage of Virtual Machine Images in an Open-Source Cloud," 2011, pp. 80-99.
Nicolae, Bogdan et al., "A Hybrid Local Storage Transfer Scheme for Live Migration of 1/0 Intensive Workloads," 2012, pp. 85-96.
Tran, et al., "Efficient Cooperative Backup with Decentralized Trust Management", 2012, pp. 1-25.
Tudoran, Radu et al., "Adaptive File Management for Scientific Workflows on the Azure Cloud," 2013, pp. 273-281.
Vrable, et al., "Cumulus: Filesystem Backup to the Cloud", 2009, pp. 1-28.
Yoshida et al., "Orthros: A High-Reliability Operating System with Transmigration of Processes," 2013, pp. 318-327.
Zhao, et al., Supporting Application-Tailored Grid File System Sessions with WSRF-Based Services, Advanced Computing and Information Systems Laboratory (ACIS), pp. 24-33.

* cited by examiner

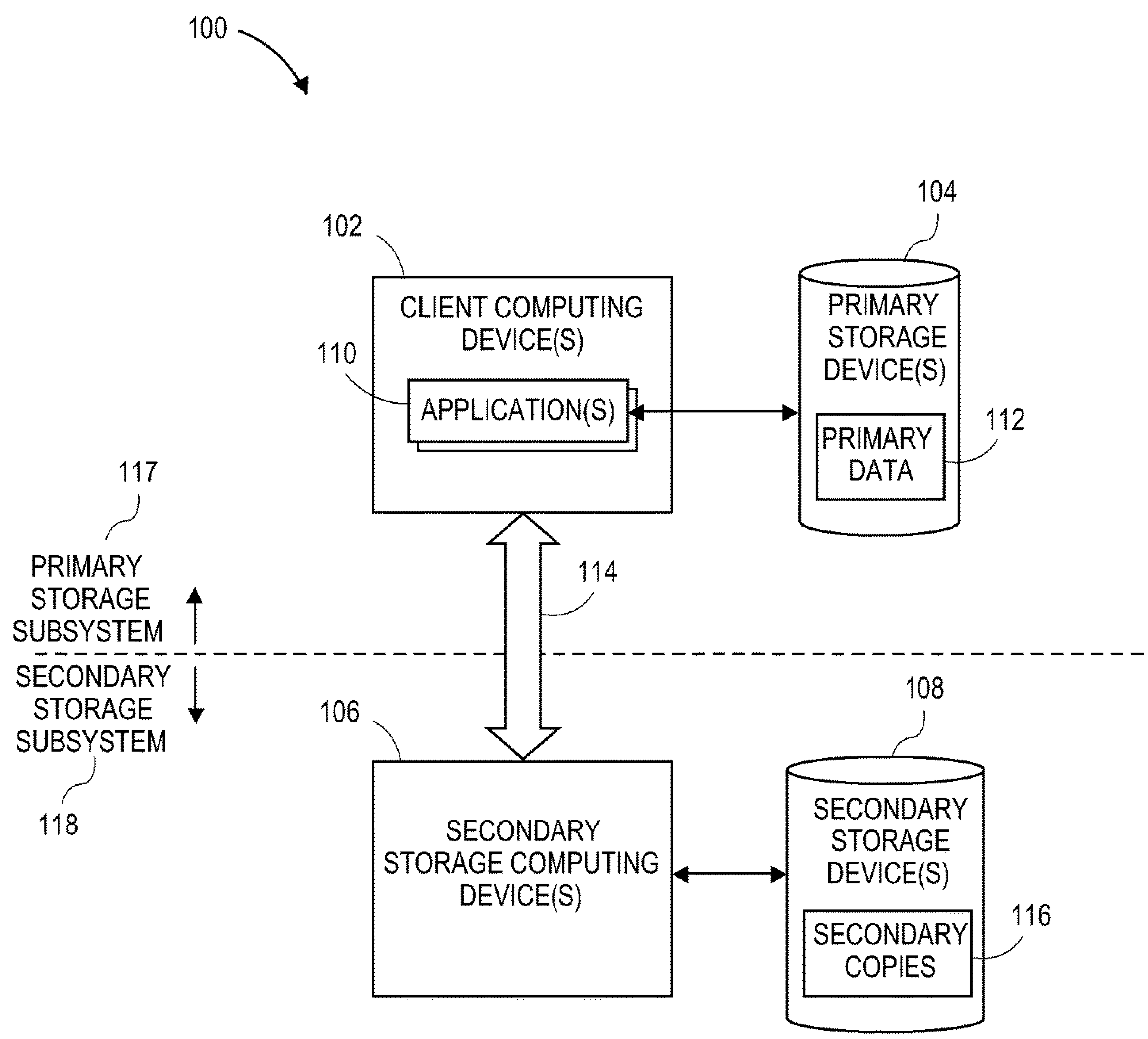

100
102
CLIENT COMPUTING DEVICE(S)
110
APPLICATION(S)
104
PRIMARY STORAGE DEVICE(S)
PRIMARY DATA
112
117
PRIMARY STORAGE SUBSYSTEM
114
SECONDARY STORAGE SUBSYSTEM
118
106
SECONDARY STORAGE COMPUTING DEVICE(S)
108
SECONDARY STORAGE DEVICE(S)
SECONDARY COPIES
116

FIG. 1A

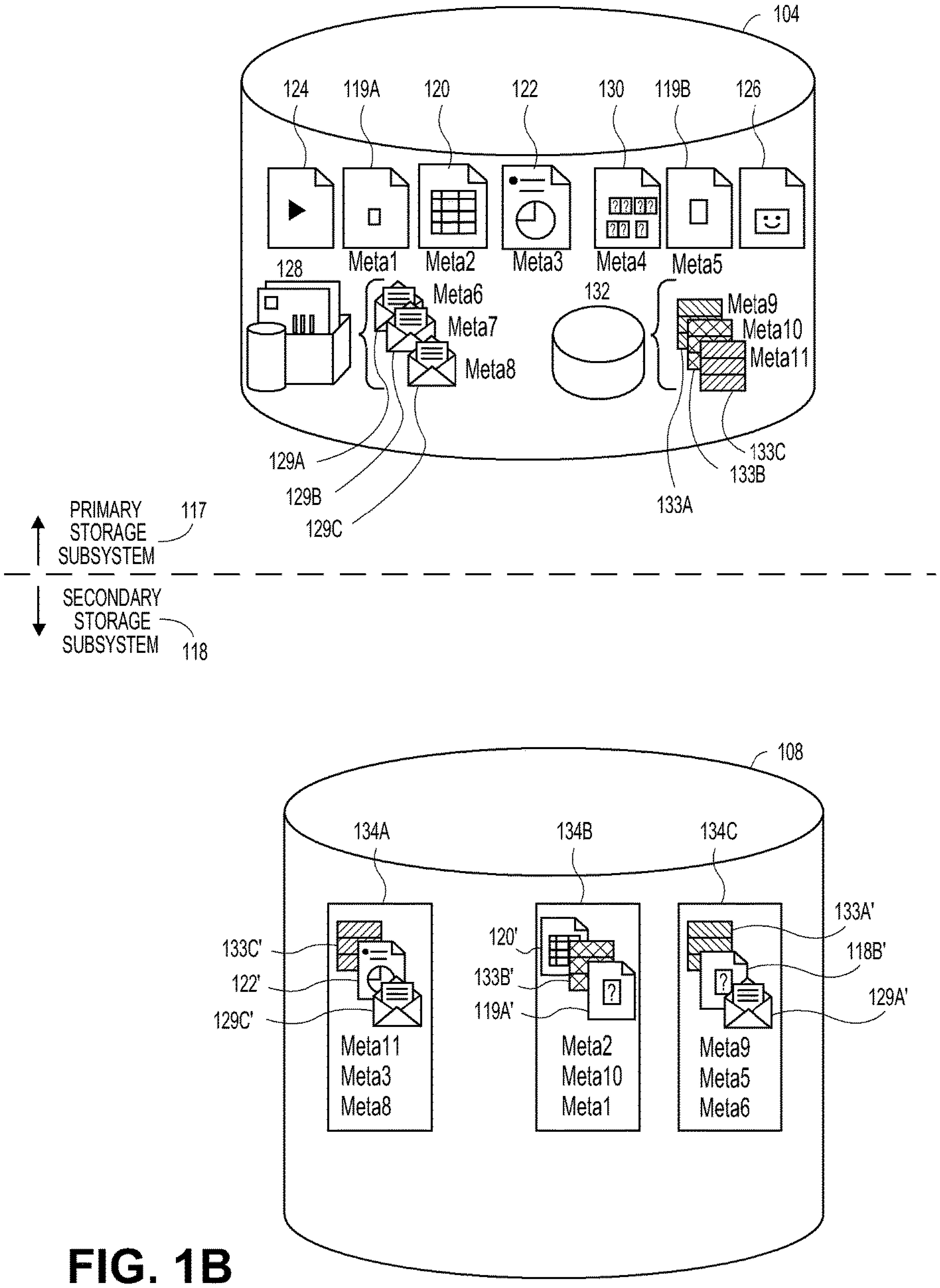

104
124
119A
120
122
130
119B
126
Meta1
Meta2
Meta3
Meta4
Meta5
128
Meta6
Meta7
Meta8
132
Meta9
Meta10
Meta11
129A
129B
129C
133C
133B
133A
PRIMARY STORAGE SUBSYSTEM
117
SECONDARY STORAGE SUBSYSTEM
118
108
134A
134B
134C
133C'
122'
129C'
Meta11
Meta3
Meta8
120'
133B'
119A'
Meta2
Meta10
Meta1
133A'
118B'
129A'
Meta9
Meta5
Meta6

FIG. 1B

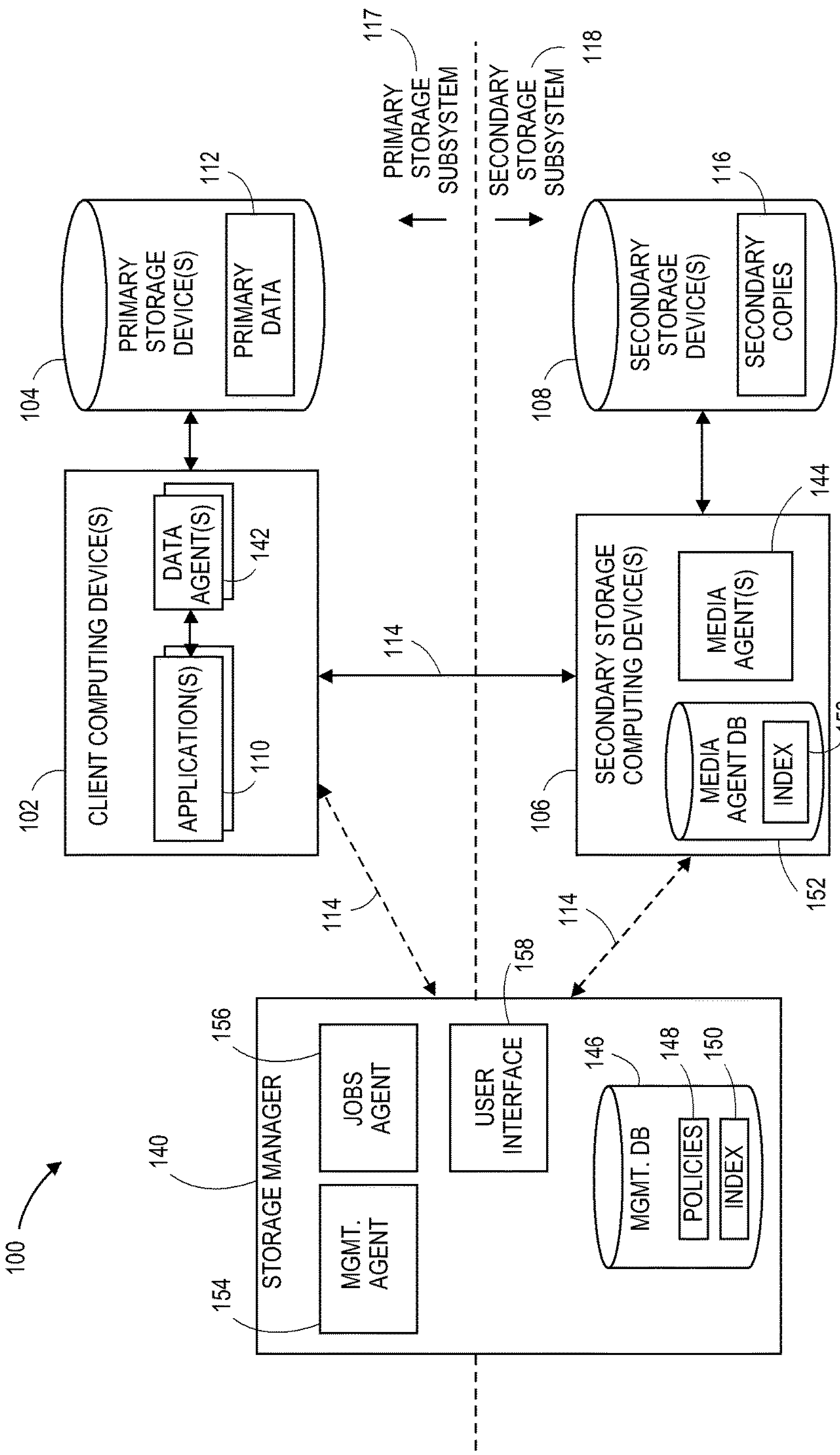

100
117
PRIMARY STORAGE SUBSYSTEM
SECONDARY STORAGE SUBSYSTEM
118
104
PRIMARY STORAGE DEVICE(S)
PRIMARY DATA
112
102
CLIENT COMPUTING DEVICE(S)
APPLICATION(S)
110
DATA AGENT(S)
142
114
108
SECONDARY STORAGE DEVICE(S)
SECONDARY COPIES
116
106
SECONDARY STORAGE COMPUTING DEVICE(S)
MEDIA AGENT DB
INDEX
153
152
MEDIA AGENT(S)
144
114
114
140
STORAGE MANAGER
154
MGMT. AGENT
156
JOBS AGENT
158
USER INTERFACE
146
MGMT. DB
148
POLICIES
150
INDEX

FIG. 1C

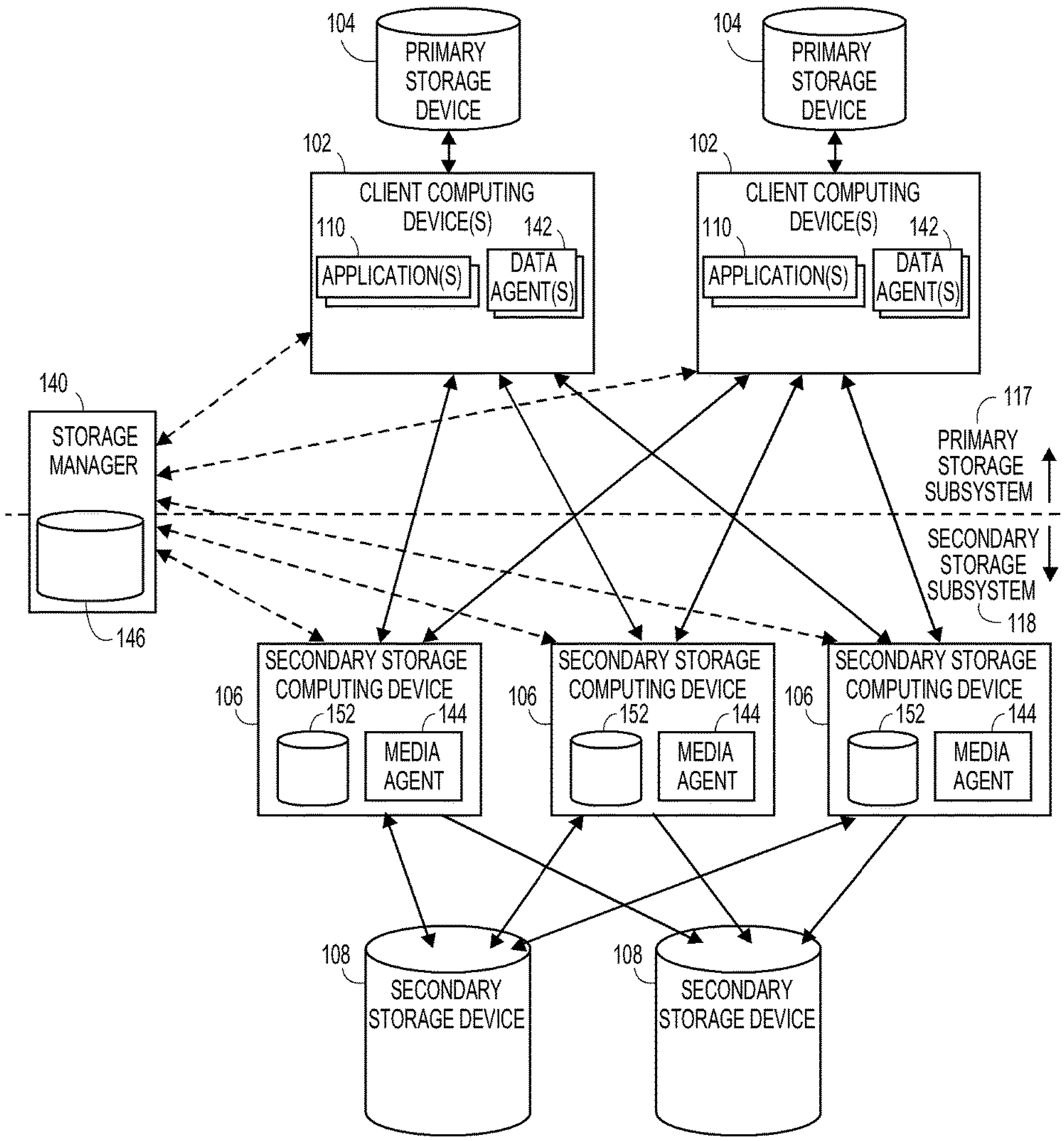

104
PRIMARY STORAGE DEVICE
104
PRIMARY STORAGE DEVICE
102
CLIENT COMPUTING DEVICE(S)
110
APPLICATION(S)
142
DATA AGENT(S)
102
CLIENT COMPUTING DEVICE(S)
110
APPLICATION(S)
142
DATA AGENT(S)
140
STORAGE MANAGER
146
117
PRIMARY STORAGE SUBSYSTEM
SECONDARY STORAGE SUBSYSTEM
118
106
SECONDARY STORAGE COMPUTING DEVICE
152
144
MEDIA AGENT
106
SECONDARY STORAGE COMPUTING DEVICE
152
144
MEDIA AGENT
106
SECONDARY STORAGE COMPUTING DEVICE
152
144
MEDIA AGENT
108
SECONDARY STORAGE DEVICE
108
SECONDARY STORAGE DEVICE

FIG. 1D

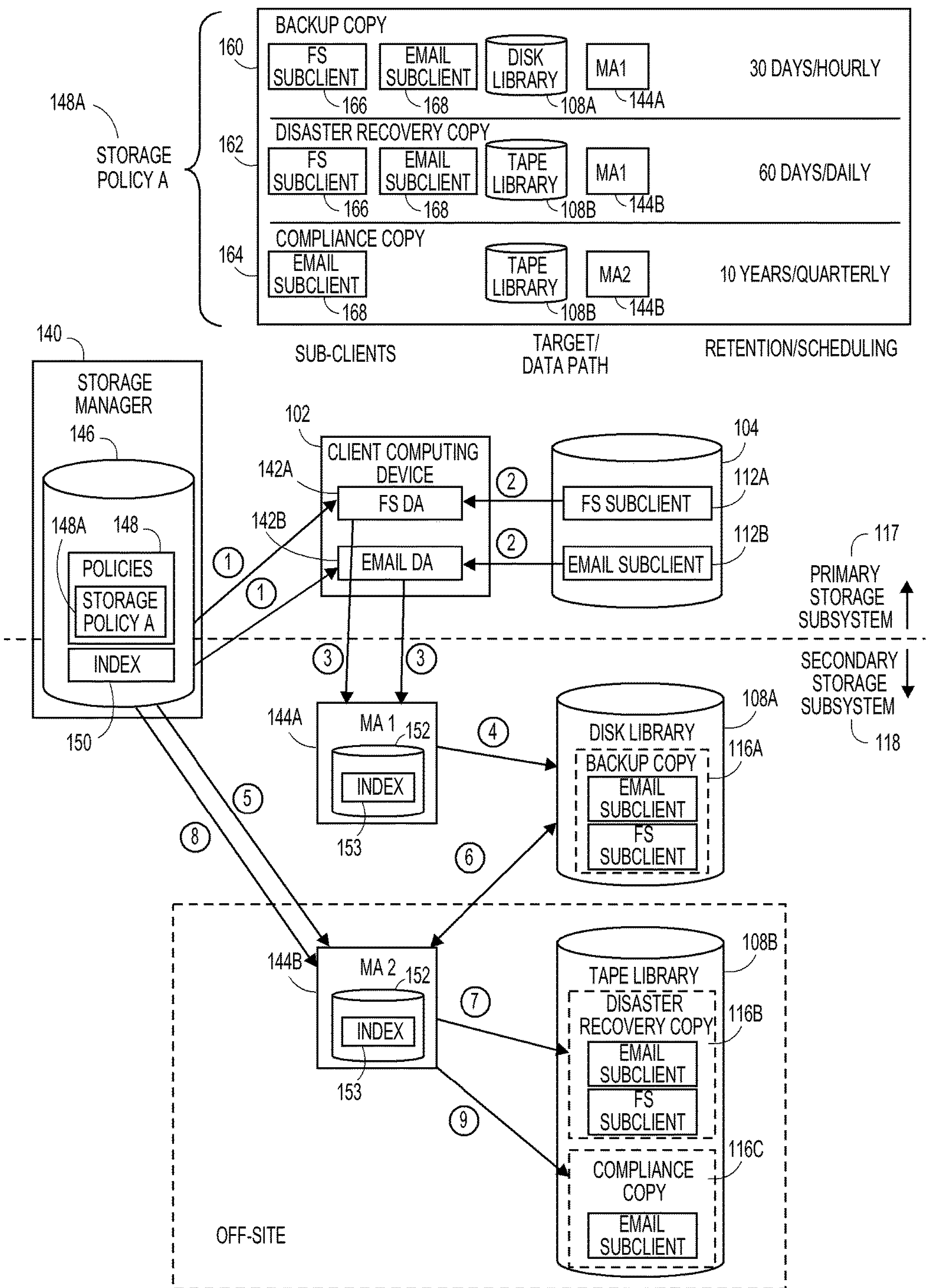

148A
STORAGE POLICY A
160
BACKUP COPY
FS SUBCLIENT
166
EMAIL SUBCLIENT
168
DISK LIBRARY
108A
MA1
144A
30 DAYS/HOURLY
162
DISASTER RECOVERY COPY
FS SUBCLIENT
166
EMAIL SUBCLIENT
168
TAPE LIBRARY
108B
MA1
144B
60 DAYS/DAILY
164
COMPLIANCE COPY
EMAIL SUBCLIENT
168
TAPE LIBRARY
108B
MA2
144B
10 YEARS/QUARTERLY
SUB-CLIENTS
TARGET/ DATA PATH
RETENTION/SCHEDULING
140
STORAGE MANAGER
146
148A
148
POLICIES
STORAGE POLICY A
INDEX
150
102
CLIENT COMPUTING DEVICE
142A
FS DA
142B
EMAIL DA
104
FS SUBCLIENT
112A
EMAIL SUBCLIENT
112B
117
PRIMARY STORAGE SUBSYSTEM
SECONDARY STORAGE SUBSYSTEM
118
1
2
3
4
5
6
7
8
9
144A
MA 1
152
INDEX
153
DISK LIBRARY
108A
116A
BACKUP COPY
EMAIL SUBCLIENT
FS SUBCLIENT
144B
MA 2
152
INDEX
153
TAPE LIBRARY
108B
DISASTER RECOVERY COPY
116B
EMAIL SUBCLIENT
FS SUBCLIENT
116C
COMPLIANCE COPY
EMAIL SUBCLIENT
OFF-SITE

FIG. 1E

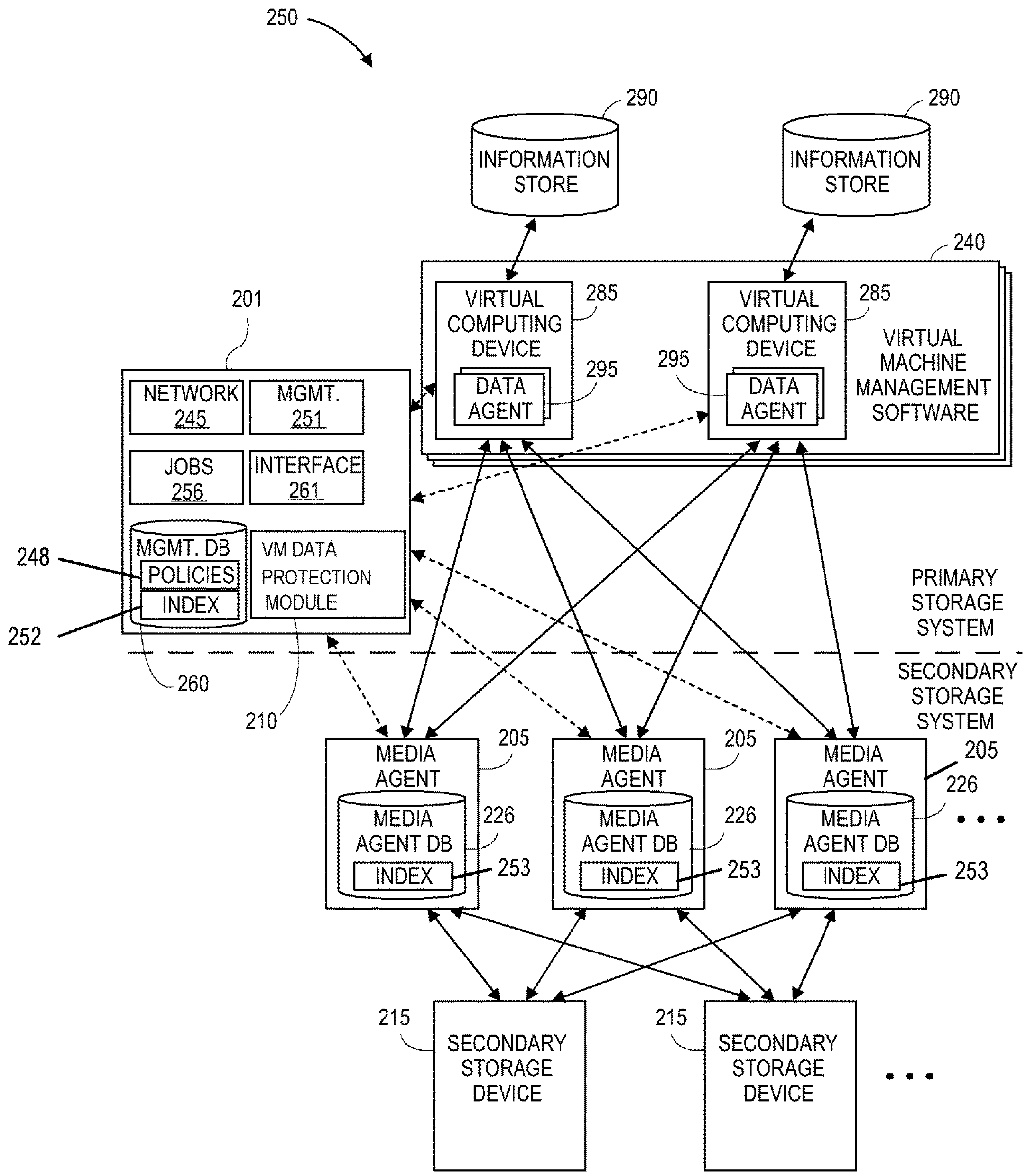

250
290
INFORMATION STORE
290
INFORMATION STORE
240
201
VIRTUAL COMPUTING DEVICE
285
295
DATA AGENT
295
VIRTUAL COMPUTING DEVICE
285
DATA AGENT
VIRTUAL MACHINE MANAGEMENT SOFTWARE
NETWORK 245
MGMT. 251
JOBS 256
INTERFACE 261
MGMT. DB
POLICIES
INDEX
VM DATA PROTECTION MODULE
248
252
260
210
PRIMARY STORAGE SYSTEM
SECONDARY STORAGE SYSTEM
MEDIA AGENT
205
MEDIA AGENT DB
226
INDEX
253
MEDIA AGENT
205
MEDIA AGENT DB
226
INDEX
253
MEDIA AGENT
205
226
MEDIA AGENT DB
INDEX
253
215
SECONDARY STORAGE DEVICE
215
SECONDARY STORAGE DEVICE

FIG. 2

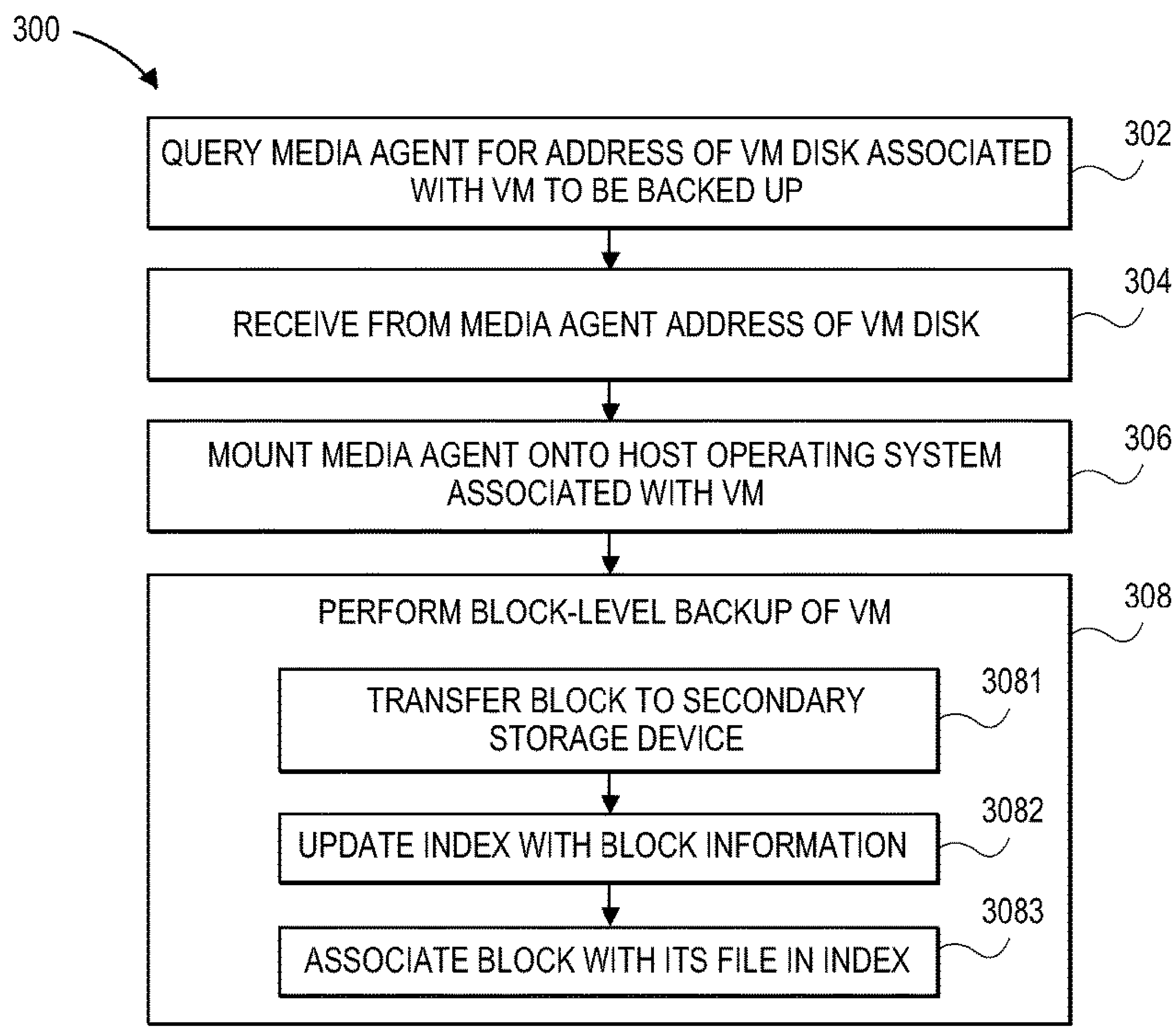

300
QUERY MEDIA AGENT FOR ADDRESS OF VM DISK ASSOCIATED WITH VM TO BE BACKED UP
302
RECEIVE FROM MEDIA AGENT ADDRESS OF VM DISK
304
MOUNT MEDIA AGENT ONTO HOST OPERATING SYSTEM ASSOCIATED WITH VM
306
PERFORM BLOCK-LEVEL BACKUP OF VM
308
TRANSFER BLOCK TO SECONDARY STORAGE DEVICE
3081
UPDATE INDEX WITH BLOCK INFORMATION
3082
ASSOCIATE BLOCK WITH ITS FILE IN INDEX
3083

FIG. 3

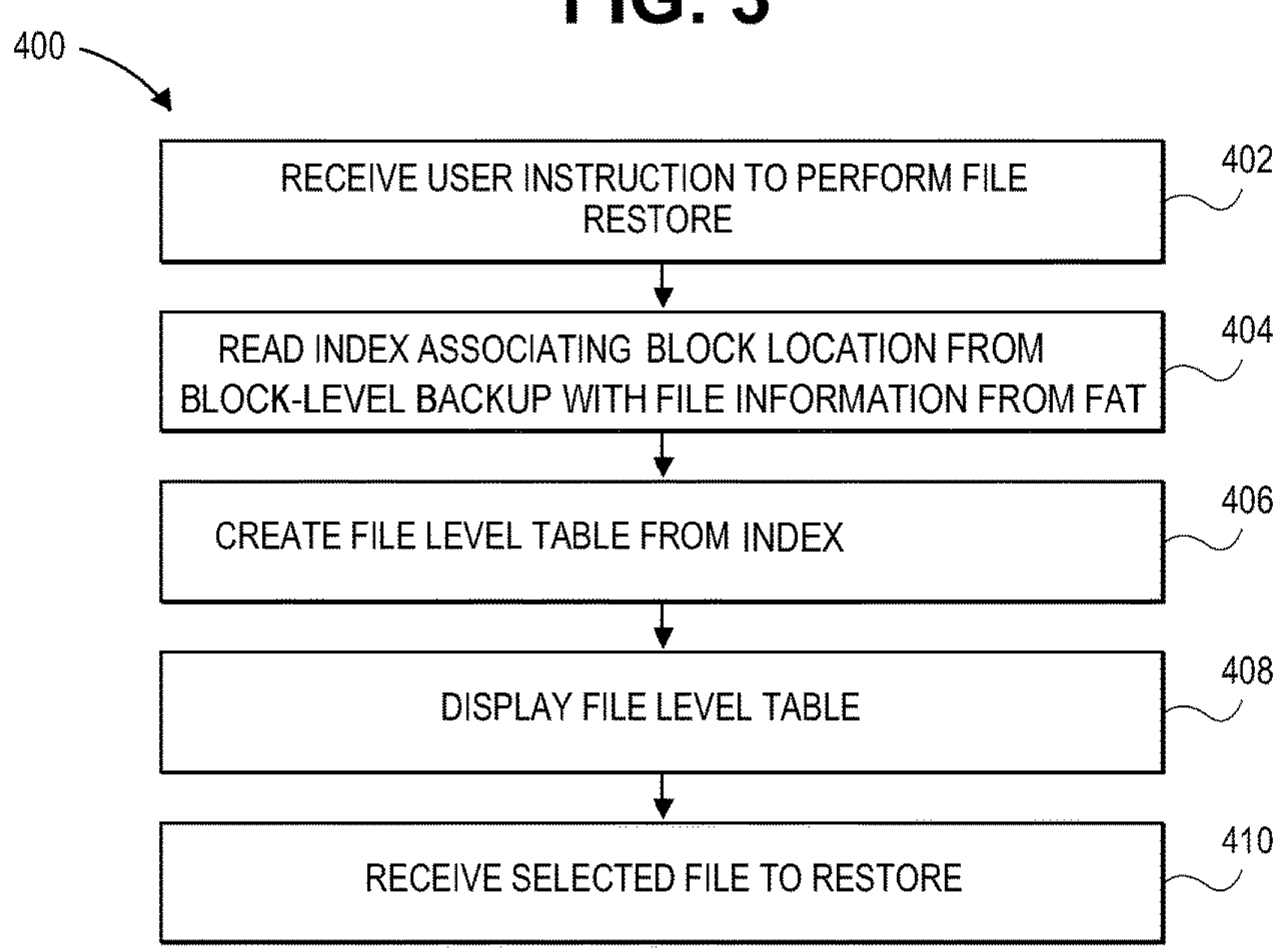

400
RECEIVE USER INSTRUCTION TO PERFORM FILE RESTORE
402
READ INDEX ASSOCIATING BLOCK LOCATION FROM BLOCK-LEVEL BACKUP WITH FILE INFORMATION FROM FAT
404
CREATE FILE LEVEL TABLE FROM INDEX
406
DISPLAY FILE LEVEL TABLE
408
RECEIVE SELECTED FILE TO RESTORE
410

FIG. 4

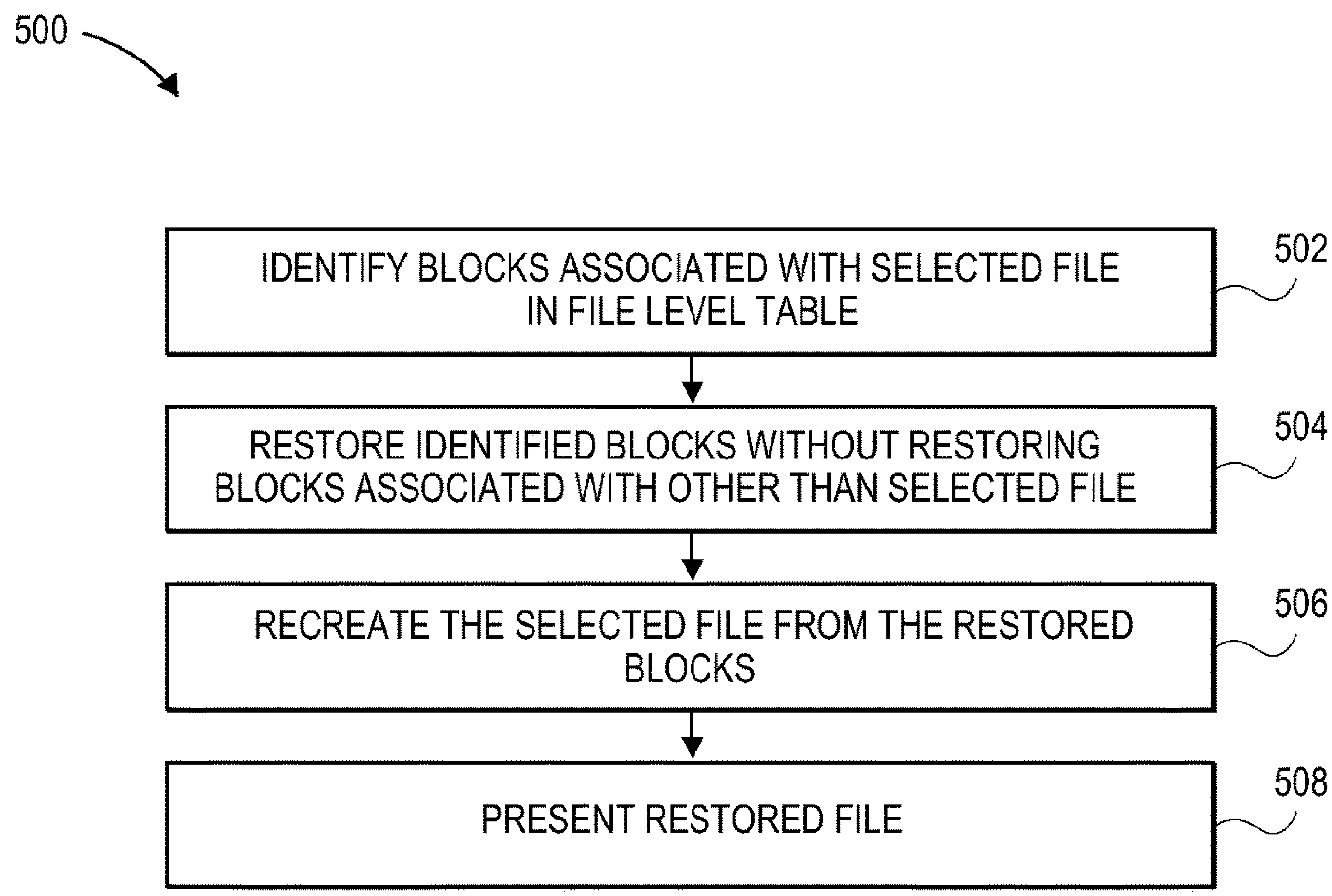

500
IDENTIFY BLOCKS ASSOCIATED WITH SELECTED FILE IN FILE LEVEL TABLE
502
RESTORE IDENTIFIED BLOCKS WITHOUT RESTORING BLOCKS ASSOCIATED WITH OTHER THAN SELECTED FILE
504
RECREATE THE SELECTED FILE FROM THE RESTORED BLOCKS
506
PRESENT RESTORED FILE
508

FIG. 5

SYSTEMS AND METHODS TO PROCESS BLOCK-LEVEL BACKUP FOR SELECTIVE FILE RESTORATION FOR VIRTUAL MACHINES

INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS

Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57.

BACKGROUND

Businesses worldwide recognize the commercial value of their data and seek reliable, cost-effective ways to protect the information stored on their computer networks while minimizing impact on productivity. Protecting information is often part of a routine process that is performed within an organization.

A company might back up critical computing systems such as databases, file servers, web servers, and so on as part of a daily, weekly, or monthly maintenance schedule. The company may similarly protect computing systems used by each of its employees, such as those used by an accounting department, marketing department, engineering department, and so forth.

Given the rapidly expanding volume of data under management, companies also continue to seek innovative techniques for managing data growth, in addition to protecting data. For instance, companies often implement migration techniques for moving data to lower cost storage over time and data reduction techniques for reducing redundant data, pruning lower priority data, etc.

Enterprises also increasingly view their stored data as a valuable asset. Along these lines, customers are looking for solutions that not only protect and manage, but also leverage their data. For instance, solutions providing data analysis capabilities, improved data presentation and access features, and the like, are in increasing demand.

Increasingly, companies are turning to virtualized computing devices to store, manipulate, and display information that is constantly subject to change. The term virtualization in the computing arts can refer to the creation of a virtual instance of an entity (e.g., a hardware platform, operating system, storage device or network resource, etc.) that behaves like a physical instance. For instance, a virtual machine can be a software representation of a physical machine. Companies currently use virtualization for a variety of purposes, such as to reduce the number of physical servers or other computers by instantiating multiple virtual machines on a single physical host computer. In this manner, virtualization can be used to centralize administrative tasks while improving scalability and work loads, and can be an important tool for maximizing hardware utilization.

SUMMARY

The benefits of virtualization are compelling and are driving the transition to large scale virtual machine deployments. Cost savings are recognized through consolidation or business flexibility and agility inherent in cloud architectures. For these and other reasons, virtualization technologies are being rapidly deployed.

Virtual machines have the similar support, security, and compliance issues as physical machines. One data protection

tool used for virtual machines is a block-level backup of an information store. An incremental copy that is a replica of the changes to files in a primary information store is created each time a backup is performed. A series of block-level backups are stored on a secondary storage device and track changes to the data in the primary storage device. The block-level backups can be rolled back to a point in time to recover the data at the time when the backup occurred. However, in some embodiments, all of the blocks are recovered, the data is reconstructed from the recovered blocks, and then a specific file can be selected from the recovered data for presentation to the user. In other embodiments, all of the blocks pertaining to a particular file are recovered, multiple versions of the file are reconstructed from the recovered blocks, and then a specific file version can be selected from the reconstructed data for presentation to the user. It is time consuming and inefficient to reconstruct data other than that selected by the user.

Due to the above challenges, it can be important to provide efficient, user-friendly tools for providing access to protected data. Systems and methods are provided herein to protect virtual machine data at a block level and restore the block-level data at a file level.

Certain embodiments relate to a method to process block-level data protection of virtual machine files for selective file-level restoration in a data management system. The method comprises automatically identifying with computer hardware an information store comprising virtual files associated with a virtual machine, where the virtual machine is associated with a media agent and a host operating system having a file allocation table (FAT) comprising file location information for each virtual file within the information store, and where the media agent accesses the FAT during a block-level backup of the virtual machine. The method further comprises automatically transferring with the computer hardware blocks of data comprising virtual files to be backed up from the information store to a secondary storage device to create transferred blocks of data in the secondary storage device, automatically updating with the computer hardware a file index associating a location of each block of data in the information store with a location of a corresponding transferred block of data in the secondary storage device, and automatically associating in the file index with the computer hardware the file location information for the virtual files to be backed up in each block of data with the location of the corresponding transferred block of data in the secondary storage device.

In an embodiment, the method of further comprises automatically retrieving with the computer hardware the file location information from the FAT by the media agent. In another embodiment, the file location information comprises, for each virtual file, a linked list of one or more clusters across which the virtual file is stored on the information store. In a further embodiment, a storage manager instructs the media agent to attach to the host operating system underlying the virtual machine. In a yet further embodiment, a storage manager instructs the host operating system underlying the virtual machine to attach the media agent. In an embodiment, a storage manager instructs the media agent to perform the block-level backup of the virtual machine and to create the file index by determining which blocks of data relate to which virtual files based at least in part on the file location information stored in the FAT of the host operating system. In another embodiment, the media agent comprises a media agent index and the file index is associated with the media agent index. In a further embodiment, the media agent comprises a media agent index which incorporates the file index. In a yet further embodiment, the method further comprises automatically querying with the computer hardware the media agent for an address of a virtual machine disk associated with the virtual machine, wherein the media agent looks up the address in a media agent index associated with the media agent, and automatically receiving with the computer hardware the address in the information store of the virtual machine disk from the media agent. In another embodiment, the method further comprising creating with the computer hardware a second virtual machine comprising the media agent in virtual machine management software.

According to certain embodiments, a system to process block-level data protection of virtual machine files for selective file-level restoration in a data management system is disclosed. The system comprises computer hardware and computer-readable storage comprising computer-readable instructions that, when executed by the computer hardware, cause the computer hardware to perform operations defined by the computer-readable instructions. The computer-readable instructions are configured to automatically identify an information store comprising virtual files associated with a virtual machine, where the virtual machine is associated with a media agent and a host operating system having a file allocation table (FAT) comprising file location information for each virtual file within the information store, and where the media agent accesses the FAT during a block-level backup of the virtual machine. The computer-readable instructions are further configured to automatically transfer blocks of data comprising virtual files to be backed up from the information store to a secondary storage device to create transferred blocks of data in the secondary storage device, automatically update a file index associating a location of each block of data in the information store with a location of a corresponding transferred block of data in the secondary storage device, and automatically associate in the file index the file location information for the virtual files to be backed up in each block of data with the location of the corresponding transferred block of data in the secondary storage device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a block diagram illustrating an exemplary information management system.

FIG. **1**B is a detailed view of a primary storage device, a secondary storage device, and some examples of primary data and secondary copy data.

FIG. **1**C is a block diagram of an exemplary information management system including a storage manager, one or more data agents, and one or more media agents.

FIG. **1**D is a block diagram illustrating a scalable information management system.

FIG. **1**E illustrates certain secondary copy operations according to an exemplary storage policy.

FIG. **2** is a block diagram illustrating an exemplary information management system comprising virtual machines.

FIG. **3** illustrates a flow chart of an exemplary embodiment of a process usable by the system of FIG. **2** to perform a block-level backup with file-level restore capability for virtual machines.

FIG. **4** illustrates a flow chart of an exemplary embodiment of a process usable by the system of FIG. **2** to select specific virtual machine restore files from a block-level backup.

FIG. **5** illustrates a flow chart of an exemplary embodiment of a process usable by the system of FIG. **2** to restore a selected virtual machine file from a block-level backup without restoring blocks associated with files other than the selected virtual machine file.

DETAILED DESCRIPTION

Systems and methods are described herein to protect virtual machine data at a block level and restore the protected data at a file level. Further examples of systems and methods for 1) processing of blocks during virtual machine backup; 2) selecting specific virtual machine files to restore from the block-level backup using a user interface; and 3) restoring selected virtual machine files from the block-level backup are described below with respect to FIGS. **2**-**5**.

Moreover, it will be appreciated that data generated by information management systems such as those that will now be described with respect to FIGS. **1**A-**1**E can be protected as well. And, as will be described, the componentry for implementing secondary data operations can be incorporated into such systems.

Information Management System Overview

With the increasing importance of protecting and leveraging data, organizations simply cannot afford to take the risk of losing critical data. Moreover, runaway data growth and other modern realities make protecting and managing data an increasingly difficult task. There is therefore a need for efficient, powerful, and user-friendly solutions for protecting and managing data.

Depending on the size of the organization, there are typically many data production sources which are under the purview of tens, hundreds, or even thousands of employees or other individuals. In the past, individual employees were sometimes responsible for managing and protecting their data. A patchwork of hardware and software point solutions have been applied in other cases. These solutions were often provided by different vendors and had limited or no interoperability.

Certain embodiments described herein provide systems and methods capable of addressing these and other shortcomings of prior approaches by implementing unified, organization-wide information management. FIG. **1**A shows one such information management system **100**, which generally includes combinations of hardware and software configured to protect and manage data and metadata generated and used by the various computing devices in the information management system **100**.

The organization which employs the information management system **100** may be a corporation or other business entity, non-profit organization, educational institution, household, governmental agency, or the like.

Generally, the systems and associated components described herein may be compatible with and/or provide some or all of the functionality of the systems and corresponding components described in one or more of the following U.S. patents and patent application publications assigned to CommVault Systems, Inc., each of which is hereby incorporated in its entirety by reference herein:

- U.S. Pat. Pub. No. 2010/0332456, entitled "DATA OBJECT STORE AND SERVER FOR A CLOUD STORAGE ENVIRONMENT, INCLUDING DATA DEDUPLICATION AND DATA MANAGEMENT ACROSS MULTIPLE CLOUD STORAGE SITES";
- U.S. Pat. No. 7,035,880, entitled "MODULAR BACKUP AND RETRIEVAL SYSTEM USED IN CONJUNCTION WITH A STORAGE AREA NETWORK";

U.S. Pat. No. 7,343,453, entitled "HIERARCHICAL SYSTEMS AND METHODS FOR PROVIDING A UNIFIED VIEW OF STORAGE INFORMATION";
U.S. Pat. No. 7,395,282, entitled "HIERARCHICAL BACKUP AND RETRIEVAL SYSTEM";
U.S. Pat. No. 7,246,207, entitled "SYSTEM AND METHOD FOR DYNAMICALLY PERFORMING STORAGE OPERATIONS IN A COMPUTER NETWORK";
U.S. Pat. No. 7,747,579, entitled "METABASE FOR FACILITATING DATA CLASSIFICATION";
U.S. Pat. No. 8,229,954, entitled "MANAGING COPIES OF DATA";
U.S. Pat. No. 7,617,262, entitled "SYSTEM AND METHODS FOR MONITORING APPLICATION DATA IN A DATA REPLICATION SYSTEM";
U.S. Pat. No. 7,529,782, entitled "SYSTEM AND METHODS FOR PERFORMING A SNAPSHOT AND FOR RESTORING DATA";
U.S. Pat. No. 8,230,195, entitled "SYSTEM AND METHOD FOR PERFORMING AUXILIARY STORAGE OPERATIONS";
U.S. Pat. Pub No. 2012/0084268, entitled "CONTENT-ALIGNED, BLOCK-BASED DEDUPLICATION";
U.S. Pat. Pub. No. 2006/0224846, entitled "SYSTEM AND METHOD TO SUPPORT SINGLE INSTANCE STORAGE OPERATIONS";
U.S. Pat. Pub. No. 2009/0329534, entitled "APPLICATION-AWARE AND REMOTE SINGLE INSTANCE DATA MANAGEMENT";
U.S. Pat. Pub. No. 2012/0150826, entitled "DISTRIBUTED DEDUPLICATED STORAGE SYSTEM";
U.S. Pat. Pub. No. 2012/0150818, entitled "CLIENT-SIDE REPOSITORY IN A NETWORKED DEDUPLICATED STORAGE SYSTEM";
U.S. Pat. No. 8,170,995, entitled "METHOD AND SYSTEM FOR OFFLINE INDEXING OF CONTENT AND CLASSIFYING STORED DATA"; and
U.S. Pat. No. 8,156,086, entitled "SYSTEMS AND METHODS FOR STORED DATA VERIFICATION".

The illustrated information management system **100** includes one or more client computing device **102** having at least one application **110** executing thereon, and one or more primary storage devices **104** storing primary data **112**. The client computing device(s) **102** and the primary storage devices **104** may generally be referred to in some cases as a primary storage subsystem **117**.

Depending on the context, the term "information management system" can refer to generally all of the illustrated hardware and software components. Or, in other instances, the term may refer to only a subset of the illustrated components.

For instance, in some cases information management system **100** generally refers to a combination of specialized components used to protect, move, manage, manipulate and/or process data and metadata generated by the client computing devices **102**. However, the term may generally not refer to the underlying components that generate and/or store the primary data **112**, such as the client computing devices **102** themselves, the applications **110** and operating system residing on the client computing devices **102**, and the primary storage devices **104**.

As an example, "information management system" may sometimes refer only to one or more of the following components and corresponding data structures: storage managers, data agents, and media agents. These components will be described in further detail below.

Client Computing Devices

There are typically a variety of sources in an organization that produce data to be protected and managed. As just one illustrative example, in a corporate environment such data sources can be employee workstations and company servers such as a mail server, a web server, or the like. In the information management system **100**, the data generation sources include the one or more client computing devices **102**.

The client computing devices **102** may include, without limitation, one or more: workstations, personal computers, desktop computers, or other types of generally fixed computing systems such as mainframe computers and minicomputers.

The client computing devices **102** can also include mobile or portable computing devices, such as one or more laptops, tablet computers, personal data assistants, mobile phones (such as smartphones), and other mobile or portable computing devices such as embedded computers, set top boxes, vehicle-mounted devices, wearable computers, etc.

In some cases, each client computing device **102** is associated with one or more users and/or corresponding user accounts, of employees or other individuals.

The term "client computing device" is used herein because the information management system **100** generally "serves" the data management and protection needs for the data generated by the client computing devices **102**. However, the use of this term does not imply that the client computing devices **102** cannot be "servers" in other respects. For instance, a particular client computing device **102** may act as a server with respect to other devices, such as other client computing devices **102**. As just a few examples, the client computing devices **102** can include mail servers, file servers, database servers, and web servers.

The client computing devices **102** may additionally include virtualized and/or cloud computing resources. For instance, one or more virtual machines may be provided to the organization by a third-party cloud service vendor. Or, in some embodiments, the client computing devices **102** include one or more virtual machine(s) running on a virtual machine host computing device operated by the organization. As one example, the organization may use one virtual machine as a database server and another virtual machine as a mail server. A virtual machine manager (VMM) (e.g., a Hypervisor) may manage the virtual machines, and reside and execute on the virtual machine host computing device.

Each client computing device **102** may have one or more applications **110** (e.g., software applications) executing thereon which generate and manipulate the data that is to be protected from loss.

The applications **110** generally facilitate the operations of an organization (or multiple affiliated organizations), and can include, without limitation, mail server applications (e.g., Microsoft Exchange Server), file server applications, mail client applications (e.g., Microsoft Exchange Client), database applications (e.g., SQL, Oracle, SAP, Lotus Notes Database), word processing applications (e.g., Microsoft Word), spreadsheet applications, financial applications, presentation applications, browser applications, mobile applications, entertainment applications, and so on.

The applications **110** can include at least one operating system (e.g., Microsoft Windows, Mac OS X, iOS, IBM z/OS, Linux, other Unix-based operating systems, etc.), which may support one or more file systems and host the other applications **110**.

As shown, the client computing devices **102** and other components in the information management system **100** can be connected to one another via one or more communication pathways **114**. The communication pathways **114** can include one or more networks or other connection types including as any of following, without limitation: the Internet, a wide area network (WAN), a local area network (LAN), a Storage Area Network (SAN), a Fibre Channel connection, a Small Computer System Interface (SCSI) connection, a virtual private network (VPN), a token ring or TCP/IP based network, an intranet network, a point-to-point link, a cellular network, a wireless data transmission system, a two-way cable system, an interactive kiosk network, a satellite network, a broadband network, a baseband network, other appropriate wired, wireless, or partially wired/wireless computer or telecommunications networks, combinations of the same or the like. The communication pathways **114** in some cases may also include application programming interfaces (APIs) including, e.g., cloud service provider APIs, virtual machine management APIs, and hosted service provider APIs.

Primary Data and Exemplary Primary Storage Devices

Primary data **112** according to some embodiments is production data or other “live” data generated by the operating system and other applications **110** residing on a client computing device **102**. The primary data **112** is stored on the primary storage device(s) **104** and is organized via a file system supported by the client computing device **102**. For instance, the client computing device(s) **102** and corresponding applications **110** may create, access, modify, write, delete, and otherwise use primary data **112**.

Primary data **112** is generally in the native format of the source application **110**. According to certain aspects, primary data **112** is an initial or first (e.g., created before any other copies or before at least one other copy) stored copy of data generated by the source application **110**. Primary data **112** in some cases is created substantially directly from data generated by the corresponding source applications **110**.

The primary data **112** may sometimes be referred to as a “primary copy” in the sense that it is a discrete set of data. However, the use of this term does not necessarily imply that the “primary copy” is a copy in the sense that it was copied or otherwise derived from another stored version.

The primary storage devices **104** storing the primary data **112** may be relatively fast and/or expensive (e.g., a disk drive, a hard-disk array, solid state memory, etc.). In addition, primary data **112** may be intended for relatively short term retention (e.g., several hours, days, or weeks).

According to some embodiments, the client computing device **102** can access primary data **112** from the primary storage device **104** by making conventional file system calls via the operating system. Primary data **112** representing files may include structured data (e.g., database files), unstructured data (e.g., documents), and/or semi-structured data. Some specific examples are described below with respect to FIG. **1**B.

It can be useful in performing certain tasks to break the primary data **112** up into units of different granularities. In general, primary data **112** can include files, directories, file system volumes, data blocks, extents, or any other types or granularities of data objects. As used herein, a “data object” can refer to both (1) any file that is currently addressable by a file system or that was previously addressable by the file system (e.g., an archive file) and (2) a subset of such a file.

As will be described in further detail, it can also be useful in performing certain functions of the information management system **100** to access and modify metadata within the primary data **112**. Metadata generally includes information about data objects or characteristics associated with the data objects.

Metadata can include, without limitation, one or more of the following: the data owner (e.g., the client or user that generates the data), the last modified time (e.g., the time of the most recent modification of the data object), a data object name (e.g., a file name), a data object size (e.g., a number of bytes of data), information about the content (e.g., an indication as to the existence of a particular search term), to/from information for email (e.g., an email sender, recipient, etc.), creation date, file type (e.g., format or application type), last accessed time, application type (e.g., type of application that generated the data object), location/network (e.g., a current, past or future location of the data object and network pathways to/from the data object), frequency of change (e.g., a period in which the data object is modified), business unit (e.g., a group or department that generates, manages or is otherwise associated with the data object), and aging information (e.g., a schedule, such as a time period, in which the data object is migrated to secondary or long term storage), boot sectors, partition layouts, file location within a file folder directory structure, user permissions, owners, groups, access control lists [ACLs]), system metadata (e.g., registry information), combinations of the same or the like.

In addition to metadata generated by or related to file systems and operating systems, some of the applications **110** maintain indices of metadata for data objects, e.g., metadata associated with individual email messages. Thus, each data object may be associated with corresponding metadata. The use of metadata to perform classification and other functions is described in greater detail below.

Each of the client computing devices **102** are associated with and/or in communication with one or more of the primary storage devices **104** storing corresponding primary data **112**. A client computing device **102** may be considered to be “associated with” or “in communication with” a primary storage device **104** if it is capable of one or more of: storing data to the primary storage device **104**, retrieving data from the primary storage device **104**, and modifying data retrieved from a primary storage device **104**.

The primary storage devices **104** can include, without limitation, disk drives, hard-disk arrays, semiconductor memory (e.g., solid state drives), and network attached storage (NAS) devices. In some cases, the primary storage devices **104** form part of a distributed file system. The primary storage devices **104** may have relatively fast I/O times and/or are relatively expensive in comparison to the secondary storage devices **108**. For example, the information management system **100** may generally regularly access data and metadata stored on primary storage devices **104**, whereas data and metadata stored on the secondary storage devices **108** is accessed relatively less frequently.

In some cases, each primary storage device **104** is dedicated to an associated client computing devices **102**. For instance, a primary storage device **104** in one embodiment is a local disk drive of a corresponding client computing device **102**. In other cases, one or more primary storage devices **104** can be shared by multiple client computing devices **102**. As one example, a primary storage device **104** can be a disk array shared by a group of client computing devices **102**, such as one of the following types of disk arrays: EMC Clariion, EMC Symmetrix, EMC Celerra, Dell EqualLogic, IBM XIV, NetApp FAS, HP EVA, and HP 3PAR.

The information management system **100** may also include hosted services (not shown), which may be hosted in some cases by an entity other than the organization that employs the other components of the information management system **100**. For instance, the hosted services may be provided by various online service providers to the organization. Such service providers can provide services including social networking services, hosted email services, or hosted productivity applications or other hosted applications).

Hosted services may include software-as-a-service (SaaS), platform-as-a-service (PaaS), application service providers (ASPs), cloud services, or other mechanisms for delivering functionality via a network. As it provides services to users, each hosted service may generate additional data and metadata under management of the information management system **100**, e.g., as primary data **112**. In some cases, the hosted services may be accessed using one of the applications **110**. As an example, a hosted mail service may be accessed via browser running on a client computing device **102**.

Secondary Copies and Exemplary Secondary Storage Devices

The primary data **112** stored on the primary storage devices **104** may be compromised in some cases, such as when an employee deliberately or accidentally deletes or overwrites primary data **112** during their normal course of work. Or the primary storage devices **104** can be damaged or otherwise corrupted.

For recovery and/or regulatory compliance purposes, it is therefore useful to generate copies of the primary data **112**. Accordingly, the information management system **100** includes one or more secondary storage computing devices **106** and one or more secondary storage devices **108** configured to create and store one or more secondary copies **116** of the primary data **112** and associated metadata. The secondary storage computing devices **106** and the secondary storage devices **108** may be referred to in some cases as a secondary storage subsystem **118**.

Creation of secondary copies **116** can help meet information management goals, such as: restoring data and/or metadata if an original version (e.g., of primary data **112**) is lost (e.g., by deletion, corruption, or disaster); allowing point-in-time recovery; complying with regulatory data retention and electronic discovery (e-discovery) requirements; reducing utilized storage capacity; facilitating organization and search of data; improving user access to data files across multiple computing devices and/or hosted services; and implementing data retention policies.

Types of secondary copy operations can include, without limitation, backup operations, archive operations, snapshot operations, replication operations (e.g., continuous data replication [CDR]), data retention policies such as or information lifecycle management and hierarchical storage management operations, and the like. These specific types operations are discussed in greater detail below.

Regardless of the type of secondary copy operation, the client computing devices **102** access or receive primary data **112** and communicate the data, e.g., over the communication pathways **114**, for storage in the secondary storage device(s) **108**.

A secondary copy **116** can comprise a separate stored copy of application data that is derived from one or more earlier created, stored copies (e.g., derived from primary data **112** or another secondary copy **116**). Secondary copies **116** can include point-in-time data, and may be intended for relatively long-term retention (e.g., weeks, months or years), before some or all of the data is moved to other storage or is discarded.

In some cases, a secondary copy **116** is a copy of application data created and stored subsequent to at least one other stored instance (e.g., subsequent to corresponding primary data **112** or to another secondary copy **116**), in a different storage device than at least one previous stored copy, and/or remotely from at least one previous stored copy. Secondary copies **116** may be stored in relatively slow and/or low cost storage (e.g., magnetic tape). A secondary copy **116** may be stored in a backup or archive format, or in some other format different than the native source application format or other primary data format.

In some cases, secondary copies **116** are indexed so users can browse and restore at another point in time. After creation of a secondary copy **116** representative of certain primary data **112**, a pointer or other location indicia (e.g., a stub) may be placed in primary data **112**, or be otherwise associated with primary data **112** to indicate the current location on the secondary storage device(s) **108**.

Since an instance a data object or metadata in primary data **112** may change over time as it is modified by an application **110** (or hosted service or the operating system), the information management system **100** may create and manage multiple secondary copies **116** of a particular data object or metadata, each representing the state of the data object in primary data **112** at a particular point in time. Moreover, since an instance of a data object in primary data **112** may eventually be deleted from the primary storage device **104** and the file system, the information management system **100** may continue to manage point-in-time representations of that data object, even though the instance in primary data **112** no longer exists.

For virtualized computing devices the operating system and other applications **110** of the client computing device(s) **102** may execute within or under the management of virtualization software (e.g., a VMM), and the primary storage device(s) **104** may comprise a virtual disk created on a physical storage device. The information management system **100** may create secondary copies **116** of the files or other data objects in a virtual disk file and/or secondary copies **116** of the entire virtual disk file itself (e.g., of an entire .vmdk file).

Secondary copies **116** may be distinguished from corresponding primary data **112** in a variety of ways, some of which will now be described. First, as discussed, secondary copies **116** can be stored in a different format (e.g., backup, archive, or other non-native format) than primary data **112**. For this or other reasons, secondary copies **116** may not be directly useable by the applications **110** of the client computing device **102**, e.g., via standard system calls or otherwise without modification, processing, or other intervention by the information management system **100**.

Secondary copies **116** are also often stored on a secondary storage device **108** that is inaccessible to the applications **110** running on the client computing devices **102** (and/or hosted services). Some secondary copies **116** may be "offline copies," in that they are not readily available (e.g. not mounted to tape or disk). Offline copies can include copies of data that the information management system **100** can access without human intervention (e.g. tapes within an automated tape library, but not yet mounted in a drive), and copies that the information management system **100** can access only with at least some human intervention (e.g. tapes located at an offsite storage site).

The secondary storage devices **108** can include any suitable type of storage device such as, without limitation, one or more tape libraries, disk drives or other magnetic, non-tape storage devices, optical media storage devices, solid state storage devices, NAS devices, combinations of the same, and the like. In some cases, the secondary storage devices **108** are provided in a cloud (e.g. a private cloud or one operated by a third-party vendor).

The secondary storage device(s) **108** in some cases comprises a disk array or a portion thereof. In some cases, a single storage device (e.g., a disk array) is used for storing both primary data **112** and at least some secondary copies **116**. In one example, a disk array capable of performing hardware snapshots stores primary data **112** and creates and stores hardware snapshots of the primary data **112** as secondary copies **116**.

The Use of Intermediary Devices for Creating Secondary Copies

Creating secondary copies can be a challenging task. For instance, there can be hundreds or thousands of client computing devices **102** continually generating large volumes of primary data **112** to be protected. Also, there can be significant overhead involved in the creation of secondary copies **116**. Moreover, secondary storage devices **108** may be special purpose components, and interacting with them can require specialized intelligence.

In some cases, the client computing devices **102** interact directly with the secondary storage device **108** to create the secondary copies **116**. However, in view of the factors described above, this approach can negatively impact the ability of the client computing devices **102** to serve the applications **110** and produce primary data **112**. Further, the client computing devices **102** may not be optimized for interaction with the secondary storage devices **108**.

Thus, in some embodiments, the information management system **100** includes one or more software and/or hardware components which generally act as intermediaries between the client computing devices **102** and the secondary storage devices **108**. In addition to off-loading certain responsibilities from the client computing devices **102**, these intermediary components can provide other benefits. For instance, as discussed further below with respect to FIG. **1**D, distributing some of the work involved in creating secondary copies **116** can enhance scalability.

The intermediary components can include one or more secondary storage computing devices **106** as shown in FIG. **1**A and/or one or more media agents, which can be software modules residing on corresponding secondary storage computing devices **106** (or other appropriate devices). Media agents are discussed below (e.g., with respect to FIGS. **1**C-**1**E).

The secondary storage computing device(s) **106** can comprise any appropriate type of computing device and can include, without limitation, any of the types of fixed and portable computing devices described above with respect to the client computing devices **102**. In some cases, the secondary storage computing device(s) **106** include specialized hardware and/or software componentry for interacting with the secondary storage devices **108**.

To create a secondary copy **116**, the client computing device **102** communicates the primary data **112** to be copied (or a processed version thereof) to the designated secondary storage computing device **106**, via the communication pathway **114**. The secondary storage computing device **106** in turn conveys the received data (or a processed version thereof) to the secondary storage device **108**. In some such configurations, the communication pathway **114** between the client computing device **102** and the secondary storage computing device **106** comprises a portion of a LAN, WAN or SAN. In other cases, at least some client computing devices **102** communicate directly with the secondary storage devices **108** (e.g., via Fibre Channel or SCSI connections).

Exemplary Primary Data and an Exemplary Secondary Copy

FIG. **1**B is a detailed view showing some specific examples of primary data stored on the primary storage device(s) **104** and secondary copy data stored on the secondary storage device(s) **108**, with other components in the system removed for the purposes of illustration. Stored on the primary storage device(s) **104** are primary data objects including word processing documents **119**A-B, spreadsheets **120**, presentation documents **122**, video files **124**, image files **126**, email mailboxes **128** (and corresponding email messages **129**A-C), html/xml or other types of markup language files **130**, databases **132** and corresponding tables **133**A-**133**C).

Some or all primary data objects are associated with a primary copy of object metadata (e.g., "Meta**1**-**11**"), which may be file system metadata and/or application specific metadata. Stored on the secondary storage device(s) **108** are secondary copy objects **134**A-C which may include copies of or otherwise represent corresponding primary data objects and metadata.

As shown, the secondary copy objects **134**A-C can individually represent more than one primary data object. For example, secondary copy data object **134**A represents three separate primary data objects **133**C, **122** and **129**C (represented as **133**C', **122'** and **129**C', respectively). Moreover, as indicated by the prime mark ('), a secondary copy object may store a representation of a primary data object or metadata differently than the original format, e.g., in a compressed, encrypted, deduplicated, or other modified format.

Exemplary Information Management System Architecture

The information management system **100** can incorporate a variety of different hardware and software components, which can in turn be organized with respect to one another in many different configurations, depending on the embodiment. There are critical design choices involved in specifying the functional responsibilities of the components and the role of each component in the information management system **100**. For instance, as will be discussed, such design choices can impact performance as well as the adaptability of the information management system **100** to data growth or other changing circumstances.

FIG. **1**C shows an information management system **100** designed according to these considerations and which includes: a central storage or information manager **140** configured to perform certain control functions, one or more data agents **142** executing on the client computing device(s) **102** configured to process primary data **112**, and one or more media agents **144** executing on the one or more secondary storage computing devices **106** for performing tasks involving the secondary storage devices **108**.

Storage Manager

As noted, the number of components in the information management system **100** and the amount of data under management can be quite large. Managing the components and data is therefore a significant task, and a task that can grow in an often unpredictable fashion as the quantity of components and data scale to meet the needs of the organization.

For these and other reasons, according to certain embodiments, responsibility for controlling the information management system **100**, or at least a significant portion of that responsibility, is allocated to the storage manager **140**.

By distributing control functionality in this manner, the storage manager **140** can be adapted independently according to changing circumstances. Moreover, a host computing device can be selected to best suit the functions of the storage manager **140**. These and other advantages are described in further detail below with respect to FIG. **1**D.

The storage manager **140** may be a software module or other application. The storage manager generally initiates, coordinates and/or controls storage and other information management operations performed by the information management system **100**, e.g., to protect and control the primary data **112** and secondary copies **116** of data and metadata.

As shown by the dashed, arrowed lines, the storage manager **140** may communicate with and/or control some or all elements of the information management system **100**, such as the data agents **142** and media agents **144**. Thus, in certain embodiments, control information originates from the storage manager **140**, whereas payload data and metadata is generally communicated between the data agents **142** and the media agents **144** (or otherwise between the client computing device(s) **102** and the secondary storage computing device(s) **106**), e.g., at the direction of the storage manager **140**. In other embodiments, some information management operations are controlled by other components in the information management system **100** (e.g., the media agent(s) **144** or data agent(s) **142**), instead of or in combination with the storage manager **140**.

According to certain embodiments, the storage manager provides one or more of the following functions:

- initiating execution of secondary copy operations;
- managing secondary storage devices **108** and inventory/capacity of the same;
- allocating secondary storage devices **108** for secondary storage operations;
- monitoring completion of and providing status reporting related to secondary storage operations;
- tracking age information relating to secondary copies **116**, secondary storage devices **108**, and comparing the age information against retention guidelines;
- tracking movement of data within the information management system **100**;
- tracking logical associations between components in the information management system **100**;
- protecting metadata associated with the information management system **100**; and
- implementing operations management functionality.

The storage manager **140** may maintain a database **146** of management-related data and information management policies **148**. The database **146** may include a management index **150** or other data structure that stores logical associations between components of the system, user preferences and/or profiles (e.g., preferences regarding encryption, compression, or deduplication of primary or secondary copy data, preferences regarding the scheduling, type, or other aspects of primary or secondary copy or other operations, mappings of particular information management users or user accounts to certain computing devices or other components, etc.), management tasks, media containerization, or other useful data. For example, the storage manager **140** may use the index **150** to track logical associations between media agents **144** and secondary storage devices **108** and/or movement of data from primary storage devices **104** to secondary storage devices **108**.

Administrators and other employees may be able to manually configure and initiate certain information management operations on an individual basis. But while this may be acceptable for some recovery operations or other relatively less frequent tasks, it is often not workable for implementing on-going organization-wide data protection and management.

Thus, the information management system **100** may utilize information management policies **148** for specifying and executing information management operations (e.g., on an automated basis). Generally, an information management policy **148** can include a data structure or other information source that specifies a set of parameters (e.g., criteria and rules) associated with storage or other information management operations.

The storage manager database **146** may maintain the information management policies **148** and associated data, although the information management policies **148** can be stored in any appropriate location. For instance, a storage policy may be stored as metadata in a media agent database **152** or in a secondary storage device **108** (e.g., as an archive copy) for use in restore operations or other information management operations, depending on the embodiment. Information management policies **148** are described further below.

According to certain embodiments, the storage manager database **146** comprises a relational database (e.g., an SQL database) for tracking metadata, such as metadata associated with secondary copy operations (e.g., what client computing devices **102** and corresponding data were protected). This and other metadata may additionally be stored in other locations, such as at the secondary storage computing devices **106** or on the secondary storage devices **108**, allowing data recovery without the use of the storage manager **140**.

As shown, the storage manager **140** may include a jobs agent **156**, a user interface **158**, and a management agent **154**, all of which may be implemented as interconnected software modules or application programs.

The jobs agent **156** in some embodiments initiates, controls, and/or monitors the status of some or all storage or other information management operations previously performed, currently being performed, or scheduled to be performed by the information management system **100**. For instance, the jobs agent **156** may access information management policies **148** to determine when and how to initiate and control secondary copy and other information management operations, as will be discussed further.

The user interface **158** may include information processing and display software, such as a graphical user interface ("GUI"), an application program interface ("API"), or other interactive interface through which users and system processes can retrieve information about the status of information management operations (e.g., storage operations) or issue instructions to the information management system **100** and its constituent components.

The storage manager **140** may also track information that permits it to select, designate, or otherwise identify content indices, deduplication databases, or similar databases or resources or data sets within its information management cell (or another cell) to be searched in response to certain queries. Such queries may be entered by the user via interaction with the user interface **158**.

Via the user interface **158**, users may optionally issue instructions to the components in the information management system **100** regarding performance of storage and recovery operations. For example, a user may modify a schedule concerning the number of pending secondary copy operations. As another example, a user may employ the GUI to view the status of pending storage operations or to monitor the status of certain components in the information management system **100** (e.g., the amount of capacity left in a storage device).

In general, the management agent **154** allows multiple information management systems **100** to communicate with one another. For example, the information management system **100** in some cases may be one information management subsystem or "cell" of a network of multiple cells adjacent to one another or otherwise logically related in a WAN or LAN. With this arrangement, the cells may be connected to one another through respective management agents **154**.

For instance, the management agent **154** can provide the storage manager **140** with the ability to communicate with other components within the information management system **100** (and/or other cells within a larger information management system) via network protocols and application programming interfaces ("APIs") including, e.g., HTTP, HTTPS, FTP, REST, virtualization software APIs, cloud service provider APIs, and hosted service provider APIs. Inter-cell communication and hierarchy is described in greater detail in U.S. Pat. No. 7,035,880, which is incorporated by reference herein.

Data Agents

As discussed, a variety of different types of applications **110** can reside on a given client computing device **102**, including operating systems, database applications, e-mail applications, and virtual machines, just to name a few. And, as part of the as part of the process of creating and restoring secondary copies **116**, the client computing devices **102** may be tasked with processing and preparing the primary data **112** from these various different applications **110**. Moreover, the nature of the processing/preparation can differ across clients and application types, e.g., due to inherent structural and formatting differences between applications **110**.

The one or more data agent(s) **142** are therefore advantageously configured in some embodiments to assist in the performance of information management operations based on the type of data that is being protected, at a client-specific and/or application-specific level.

The data agent **142** may be a software module or component that is generally responsible for managing, initiating, or otherwise assisting in the performance of information management operations. For instance, the data agent **142** may take part in performing data storage operations such as the copying, archiving, migrating, replicating of primary data **112** stored in the primary storage device(s) **104**. The data agent **142** may receive control information from the storage manager **140**, such as commands to transfer copies of data objects, metadata, and other payload data to the media agents **144**.

In some embodiments, a data agent **142** may be distributed between the client computing device **102** and storage manager **140** (and any other intermediate components) or may be deployed from a remote location or its functions approximated by a remote process that performs some or all of the functions of data agent **142**. In addition, a data agent **142** may perform some functions provided by a media agent **144**, e.g., encryption and deduplication.

As indicated, each data agent **142** may be specialized for a particular application **110**, and the system can employ multiple data agents **142**, each of which may backup, migrate, and recover data associated with a different application **110**. For instance, different individual data agents **142** may be designed to handle Microsoft Exchange data, Lotus Notes data, Microsoft Windows file system data, Microsoft Active Directory Objects data, SQL Server data, SharePoint data, Oracle database data, SAP database data, virtual machines and/or associated data, and other types of data.

A file system data agent, for example, may handle data files and/or other file system information. If a client computing device **102** has two or more types of data, one data agent **142** may be used for each data type to copy, archive, migrate, and restore the client computing device **102** data. For example, to backup, migrate, and restore all of the data on a Microsoft Exchange server, the client computing device **102** may use one Microsoft Exchange Mailbox data agent **142** to backup the Exchange mailboxes, one Microsoft Exchange Database data agent **142** to backup the Exchange databases, one Microsoft Exchange Public Folder data agent **142** to backup the Exchange Public Folders, and one Microsoft Windows File System data agent **142** to backup the file system of the client computing device **102**. In such embodiments, these data agents **142** may be treated as four separate data agents **142** by even though they reside on the same client computing device **102**.

Other embodiments may employ one or more generic data agents **142** that can handle and process data from two or more different applications **110**, or that can handle and process multiple data types, instead of or in addition to using specialized data agents **142**. For example, one generic data agent **142** may be used to back up, migrate and restore Microsoft Exchange Mailbox data and Microsoft Exchange Database data while another generic data agent may handle Microsoft Exchange Public Folder data and Microsoft Windows File System data.

Each data agent **142** may be configured to access data and/or metadata stored in the primary storage device(s) **104** associated with the data agent **142** and process the data as appropriate. For example, during a secondary copy operation, the data agent **142** may arrange or assemble the data and metadata into one or more files having a certain format (e.g., a particular backup or archive format) before transferring the file(s) to a media agent **144** or other component. The file(s) may include a list of files or other metadata. Each data agent **142** can also assist in restoring data or metadata to primary storage devices **104** from a secondary copy **116**. For instance, the data agent **142** may operate in conjunction with the storage manager **140** and one or more of the media agents **144** to restore data from secondary storage device(s) **108**.

Media Agents

As indicated above with respect to FIG. **1**A, off-loading certain responsibilities from the client computing devices **102** to intermediary components such as the media agent(s) **144** can provide a number of benefits including improved client computing device **102** operation, faster secondary copy operation performance, and enhanced scalability. As one specific example which will be discussed below in further detail, the media agent **144** can act as a local cache of copied data and/or metadata that it has stored to the secondary storage device(s) **108**, providing improved restore capabilities.

Generally speaking, a media agent **144** may be implemented as a software module that manages, coordinates, and facilitates the transmission of data, as directed by the storage manager **140**, between a client computing device **102** and one or more secondary storage devices **108**. Whereas the storage manager **140** controls the operation of the information management system **100**, the media agent **144** generally provides a portal to secondary storage devices **108**.

Media agents **144** can comprise logically and/or physically separate nodes in the information management system **100** (e.g., separate from the client computing devices **102**, storage manager **140**, and/or secondary storage devices **108**). In addition, each media agent **144** may reside on a dedicated secondary storage computing device **106** in some cases, while in other embodiments a plurality of media agents **144** reside on the same secondary storage computing device **106**.

A media agent **144** (and corresponding media agent database **152**) may be considered to be "associated with" a particular secondary storage device **108** if that media agent **144** is capable of one or more of: routing and/or storing data to the particular secondary storage device **108**, coordinating the routing and/or storing of data to the particular secondary storage device **108**, retrieving data from the particular secondary storage device **108**, and coordinating the retrieval of data from a particular secondary storage device **108**.

While media agent(s) **144** are generally associated with one or more secondary storage devices **108**, the media agents **144** in certain embodiments are physically separate from the secondary storage devices **108**. For instance, the media agents **144** may reside on secondary storage computing devices **106** having different housings or packages than the secondary storage devices **108**. In one example, a media agent **144** resides on a first server computer and is in communication with a secondary storage device(s) **108** residing in a separate, rack-mounted RAID-based system.

In operation, a media agent **144** associated with a particular secondary storage device **108** may instruct the secondary storage device **108** (e.g., a tape library) to use a robotic arm or other retrieval means to load or eject a certain storage media, and to subsequently archive, migrate, or retrieve data to or from that media, e.g., for the purpose of restoring the data to a client computing device **102**. The media agent **144** may communicate with a secondary storage device **108** via a suitable communications link, such as a SCSI or Fiber Channel link.

As shown, each media agent **144** may maintain an associated media agent database **152**. The media agent database **152** may be stored in a disk or other storage device (not shown) that is local to the secondary storage computing device **106** on which the media agent **144** resides. In other cases, the media agent database **152** is stored remotely from the secondary storage computing device **106**.

The media agent database **152** can include, among other things, an index **153** including data generated during secondary copy operations and other storage or information management operations. The index **153** provides a media agent **144** or other component with a fast and efficient mechanism for locating secondary copies **116** or other data stored in the secondary storage devices **108**. In one configuration, a storage manager index **150** or other data structure may store data associating a client computing device **102** with a particular media agent **144** and/or secondary storage device **108**, as specified in a storage policy. A media agent index **153** or other data structure associated with the particular media agent **144** may in turn include information about the stored data.

For instance, for each secondary copy **116**, the index **153** may include metadata such as a list of the data objects (e.g., files/subdirectories, database objects, mailbox objects, etc.), a path to the secondary copy **116** on the corresponding secondary storage device **108**, location information indicating where the data objects are stored in the secondary storage device **108**, when the data objects were created or modified, etc. Thus, the index **153** includes metadata associated with the secondary copies **116** that is readily available for use in storage operations and other activities without having to be first retrieved from the secondary storage device **108**. In yet further embodiments, some or all of the data in the index **153** may instead or additionally be stored along with the data in a secondary storage device **108**, e.g., with a copy of the index **153**.

Because the index **153** maintained in the database **152** may operate as a cache, it can also be referred to as an index cache. In such cases, information stored in the index cache **153** typically comprises data that reflects certain particulars about storage operations that have occurred relatively recently. After some triggering event, such as after a certain period of time elapses, or the index cache **153** reaches a particular size, the index cache **153** may be copied or migrated to a secondary storage device(s) **108**. This information may need to be retrieved and uploaded back into the index cache **153** or otherwise restored to a media agent **144** to facilitate retrieval of data from the secondary storage device(s) **108**. In some embodiments, the cached information may include format or containerization information related to archives or other files stored on the storage device(s) **108**. In this manner, the index cache **153** allows for accelerated restores.

In some alternative embodiments the media agent **144** generally acts as a coordinator or facilitator of storage operations between client computing devices **102** and corresponding secondary storage devices **108**, but does not actually write the data to the secondary storage device **108**. For instance, the storage manager **140** (or the media agent **144**) may instruct a client computing device **102** and secondary storage device **108** to communicate with one another directly. In such a case the client computing device **102** transmits the data directly to the secondary storage device **108** according to the received instructions, and vice versa. In some such cases, the media agent **144** may still receive, process, and/or maintain metadata related to the storage operations. Moreover, in these embodiments, the payload data can flow through the media agent **144** for the purposes of populating the index cache **153** maintained in the media agent database **152**, but not for writing to the secondary storage device **108**.

The media agent **144** and/or other components such as the storage manager **140** may in some cases incorporate additional functionality, such as data classification, content indexing, deduplication, encryption, compression, and the like. Further details regarding these and other functions are described below.

Distributed, Scalable Architecture

As described, certain functions of the information management system **100** can be distributed amongst various physical and/or logical components in the system. For instance, one or more of the storage manager **140**, data agents **142**, and media agents **144** may reside on computing devices that are physically separate from one another. This architecture can provide a number of benefits.

For instance, hardware and software design choices for each distributed component can be targeted to suit its particular function. The secondary computing devices **106** on which the media agents **144** reside can be tailored for interaction with associated secondary storage devices **108** and provide fast index cache operation, among other specific tasks. Similarly, the client computing device(s) **102** can be selected to effectively service the applications **110** residing thereon, in order to efficiently produce and store primary data **112**.

Moreover, in some cases, one or more of the individual components in the information management system **100** can be distributed to multiple, separate computing devices. As one example, for large file systems where the amount of data stored in the storage management database **146** is relatively large, the management database **146** may be migrated to or otherwise reside on a specialized database server (e.g., an SQL server) separate from a server that implements the other functions of the storage manager **140**. This configuration can provide added protection because the database **146** can be protected with standard database utilities (e.g., SQL log shipping or database replication) independent from other functions of the storage manager **140**. The database **146** can be efficiently replicated to a remote site for use in the event of a disaster or other data loss incident at the primary site. Or the database **146** can be replicated to another computing device within the same site, such as to a higher performance machine in the event that a storage manager host device can no longer service the needs of a growing information management system **100**.

The distributed architecture also provides both scalability and efficient component utilization. FIG. **1D** shows an embodiment of the information management system **100** including a plurality of client computing devices **102** and associated data agents **142** as well as a plurality of secondary storage computing devices **106** and associated media agents **144**.

Additional components can be added or subtracted based on the evolving needs of the information management system **100**. For instance, depending on where bottlenecks are identified, administrators can add additional client computing devices **102**, secondary storage devices **106** (and corresponding media agents **144**), and/or secondary storage devices **108**.

Moreover, each client computing device **102** in some embodiments can communicate with any of the media agents **144**, e.g., as directed by the storage manager **140**. And each media agent **144** may be able to communicate with any of the secondary storage devices **108**, e.g., as directed by the storage manager **140**. Thus, operations can be routed to the secondary storage devices **108** in a dynamic and highly flexible manner. Further examples of scalable systems capable of dynamic storage operations are provided in U.S. Pat. No. 7,246,207, which is incorporated by reference herein.

In alternative configurations, certain components are not distributed and may instead reside and execute on the same computing device. For example, in some embodiments one or more data agents **142** and the storage manager **140** reside on the same client computing device **102**. In another embodiment, one or more data agents **142** and one or more media agents **144** reside on a single computing device.

Exemplary Types of Information Management Operations

In order to protect and leverage stored data, the information management system **100** can be configured to perform a variety of information management operations. As will be described, these operations can generally include secondary copy and other data movement operations, processing and data manipulation operations, and management operations.

Data Movement Operations

Data movement operations according to certain embodiments are generally operations that involve the copying or migration of data (e.g., payload data) between different locations in the information management system **100**. For example, data movement operations can include operations in which stored data is copied, migrated, or otherwise transferred from primary storage device(s) **104** to secondary storage device(s) **108**, from secondary storage device(s) **108** to different secondary storage device(s) **108**, or from primary storage device(s) **104** to different primary storage device(s) **104**.

Data movement operations can include by way of example, backup operations, archive operations, information lifecycle management operations such as hierarchical storage management operations, replication operations (e.g., continuous data replication operations), snapshot operations, deduplication operations, single-instancing operations, auxiliary copy operations, and the like. As will be discussed, some of these operations involve the copying, migration or other movement of data, without actually creating multiple, distinct copies. Nonetheless, some or all of these operations are referred to as "copy" operations for simplicity.

Backup Operations

A backup operation creates a copy of primary data **112** at a particular point in time. Each subsequent backup copy may be maintained independently of the first. Further, a backup copy in some embodiments is stored in a backup format. This can be in contrast to the version in primary data **112** from which the backup copy is derived, and which may instead be stored in a native format of the source application(s) **110**. In various cases, backup copies can be stored in a format in which the data is compressed, encrypted, deduplicated, and/or otherwise modified from the original application format. For example, a backup copy may be stored in a backup format that facilitates compression and/or efficient long-term storage.

Backup copies can have relatively long retention periods as compared to primary data **112**, and may be stored on media with slower retrieval times than primary data **112** and certain other types of secondary copies **116**. On the other hand, backups may have relatively shorter retention periods than some other types of secondary copies **116**, such as archive copies (described below). Backups may sometimes be stored at on offsite location.

Backup operations can include full, synthetic or incremental backups. A full backup in some embodiments is generally a complete image of the data to be protected. However, because full backup copies can consume a relatively large amount of storage, it can be useful to use a full backup copy as a baseline and only store changes relative to the full backup copy for subsequent backup copies.

For instance, a differential backup operation (or cumulative incremental backup operation) tracks and stores changes that have occurred since the last full backup. Differential backups can grow quickly in size, but can provide relatively efficient restore times because a restore can be completed in some cases using only the full backup copy and the latest differential copy.

An incremental backup operation generally tracks and stores changes since the most recent backup copy of any type, which can greatly reduce storage utilization. In some cases, however, restore times can be relatively long in comparison to full or differential backups because completing a restore operation may involve accessing a full backup in addition to multiple incremental backups.

Any of the above types of backup operations can be at the file-level, e.g., where the information management system **100** generally tracks changes to files at the file-level, and includes copies of files in the backup copy. In other cases, block-level backups are employed, where files are broken into constituent blocks, and changes are tracked at the block-level. Upon restore, the information management system **100** reassembles the blocks into files in a transparent fashion.

Far less data may actually be transferred and copied to the secondary storage devices **108** during a block-level copy than during a file-level copy, resulting in faster execution times. However, when restoring a block-level copy, the process of locating constituent blocks can sometimes result in longer restore times as compared to file-level backups. Similar to backup operations, the other types of secondary copy operations described herein can also be implemented at either the file-level or the block-level.

Archive Operations

Because backup operations generally involve maintaining a version of the copied data in primary data **112** and also maintaining backup copies in secondary storage device(s) **108**, they can consume significant storage capacity. To help reduce storage consumption, an archive operation according to certain embodiments creates a secondary copy **116** by both copying and removing source data. Or, seen another way, archive operations can involve moving some or all of the source data to the archive destination. Thus, data satisfying criteria for removal (e.g., data of a threshold age or size) from the source copy may be removed from source storage. Archive copies are sometimes stored in an archive format or other non-native application format. The source data may be primary data **112** or a secondary copy **116**, depending on the situation. As with backup copies, archive copies can be stored in a format in which the data is compressed, encrypted, deduplicated, and/or otherwise modified from the original application format.

In addition, archive copies may be retained for relatively long periods of time (e.g., years) and, in some cases, are never deleted. Archive copies are generally retained for longer periods of time than backup copies, for example. In certain embodiments, archive copies may be made and kept for extended periods in order to meet compliance regulations.

Moreover, when primary data **112** is archived, in some cases the archived primary data **112** or a portion thereof is deleted when creating the archive copy. Thus, archiving can serve the purpose of freeing up space in the primary storage device(s) **104**. Similarly, when a secondary copy **116** is archived, the secondary copy **116** may be deleted, and an archive copy can therefore serve the purpose of freeing up space in secondary storage device(s) **108**. In contrast, source copies often remain intact when creating backup copies.

Snapshot Operations

Snapshot operations can provide a relatively lightweight, efficient mechanism for protecting data. From an end-user viewpoint, a snapshot may be thought of as an "instant" image of the primary data **112** at a given point in time. In one embodiment, a snapshot may generally capture the directory structure of an object in primary data **112** such as a file or volume or other data set at a particular moment in time and may also preserve file attributes and contents. A snapshot in some cases is created relatively quickly, e.g., substantially instantly, using a minimum amount of file space, but may still function as a conventional file system backup.

A snapshot copy in many cases can be made quickly and without significantly impacting primary computing resources because large amounts of data need not be copied or moved. In some embodiments, a snapshot may exist as a virtual file system, parallel to the actual file system. Users in some cases gain read-only access to the record of files and directories of the snapshot. By electing to restore primary data **112** from a snapshot taken at a given point in time, users may also return the current file system to the state of the file system that existed when the snapshot was taken.

Some types of snapshots do not actually create another physical copy of all the data as it existed at the particular point in time, but may simply create pointers that are able to map files and directories to specific memory locations (e.g., disk blocks) where the data resides, as it existed at the particular point in time. For example, a snapshot copy may include a set of pointers derived from the file system or an application. Each pointer points to a respective stored data block, so collectively, the set of pointers reflect the storage location and state of the data object (e.g., file(s) or volume(s) or data set(s)) at a particular point in time when the snapshot copy was created.

In some embodiments, once a snapshot has been taken, subsequent changes to the file system typically do not overwrite the blocks in use at the time of the snapshot. Therefore, the initial snapshot may use only a small amount of disk space needed to record a mapping or other data structure representing or otherwise tracking the blocks that correspond to the current state of the file system. Additional disk space is usually required only when files and directories are actually modified later. Furthermore, when files are modified, typically only the pointers which map to blocks are copied, not the blocks themselves. In some embodiments, for example in the case of "copy-on-write" snapshots, when a block changes in primary storage, the block is copied to secondary storage or cached in primary storage before the block is overwritten in primary storage. The snapshot mapping of file system data is also updated to reflect the changed block(s) at that particular point in time. In some other cases, a snapshot includes a full physical copy of all or substantially all of the data represented by the snapshot. Further examples of snapshot operations are provided in U.S. Pat. No. 7,529,782, which is incorporated by reference herein.

Replication Operations

Another type of secondary copy operation is a replication operation. Some types of secondary copies **116** are used to periodically capture images of primary data **112** at particular points in time (e.g., backups, archives, and snapshots). However, it can also be useful for recovery purposes to protect primary data **112** in a more continuous fashion, by replicating the primary data **112** substantially as changes occur. In some cases a replication copy can be a mirror copy, for instance, where changes made to primary data **112** are mirrored to another location (e.g., to secondary storage device(s) **108**). By copying each write operation to the replication copy, two storage systems are kept synchronized or substantially synchronized so that they are virtually identical at approximately the same time. Where entire disk volumes are mirrored, however, mirroring can require significant amount of storage space and utilizes a large amount of processing resources.

According to some embodiments storage operations are performed on replicated data that represents a recoverable state, or "known good state" of a particular application running on the source system. For instance, in certain embodiments, known good replication copies may be viewed as copies of primary data **112**. This feature allows the system to directly access, copy, restore, backup or otherwise manipulate the replication copies as if the data was the "live", primary data **112**. This can reduce access time, storage utilization, and impact on source applications **110**, among other benefits.

Based on known good state information, the information management system **100** can replicate sections of application data that represent a recoverable state rather than rote copying of blocks of data. Examples of compatible replication operations (e.g., continuous data replication) are provided in U.S. Pat. No. 7,617,262, which is incorporated by reference herein.

Deduplication/Single-Instancing Operations

Another type of data movement operation is deduplication, which is useful to reduce the amount of data within the system. For instance, some or all of the above-described secondary storage operations can involve deduplication in some fashion. New data is read, broken down into blocks (e.g., sub-file level blocks) of a selected granularity, compared with blocks that are already stored, and only the new blocks are stored. Blocks that already exist are represented as pointers to the already stored data.

In order to stream-line the comparison process, the information management system **100** may calculate and/or store signatures (e.g., hashes) corresponding to the individual data blocks and compare the hashes instead of comparing entire data blocks. In some cases, only a single instance of each element is stored, and deduplication operations may therefore be referred to interchangeably as "single-instancing" operations. Depending on the implementation, however, deduplication or single-instancing operations can store more than one instance of certain data blocks, but nonetheless significantly reduce data redundancy. Moreover, single-instancing in some cases is distinguished from deduplication as a process of analyzing and reducing data at the file level, rather than the sub-file level.

Depending on the embodiment, deduplication blocks can be of fixed or variable length. Using variable length blocks can provide enhanced deduplication by responding to changes in the data stream, but can involve complex processing. In some cases, the information management system **100** utilizes a technique for dynamically aligning deduplication blocks (e.g., fixed-length blocks) based on changing content in the data stream, as described in U.S. Pat. Pub No. 2012/0084268, which is incorporated by reference herein.

The information management system **100** can perform deduplication in a variety of manners at a variety of locations in the information management system **100**. For instance, in some embodiments, the information management system **100** implements "target-side" deduplication by deduplicating data (e.g., secondary copies **116**) stored in the secondary storage devices **108**. In some such cases, the media agents **144** are generally configured to manage the deduplication process. For instance, one or more of the media agents **144** maintain a corresponding deduplication database that stores deduplication information (e.g., datablock signatures). Examples of such a configuration are provided in U.S. Pat. Pub. No. 2012/0150826, which is incorporated by reference herein. Deduplication can also be performed on the "source-side" (or "client-side"), e.g., to reduce the amount of traffic between the media agents **144** and the client computing device(s) **102** and/or reduce redundant data stored in the primary storage devices **104**. Examples of such deduplication techniques are provided in U.S. Pat. Pub. No. 2012/0150818, which is incorporated by reference herein.

Information Lifecycle Management and Hierarchical Storage Management Operations

In some embodiments, files and other data over their lifetime move from more expensive, quick access storage to less expensive, slower access storage. Operations associated with moving data through various tiers of storage are sometimes referred to as information lifecycle management (ILM) operations.

One type of ILM operation is a hierarchical storage management (HSM) operation. A HSM operation is generally an operation for automatically moving data between classes of storage devices, such as between high-cost and low-cost storage devices. For instance, an HSM operation may involve movement of data from primary storage devices **104** to secondary storage devices **108**, or between tiers of secondary storage devices **108**. With each tier, the storage devices may be progressively relatively cheaper, have relatively slower access/restore times, etc. For example, movement of data between tiers may occur as data becomes less important over time.

In some embodiments, an HSM operation is similar to an archive operation in that creating an HSM copy may (though not always) involve deleting some of the source data. For example, an HSM copy may include data from primary data **112** or a secondary copy **116** that is larger than a given size threshold or older than a given age threshold and that is stored in a backup format.

Often, and unlike some types of archive copies, HSM data that is removed or aged from the source copy is replaced by a logical reference pointer or stub. The reference pointer or stub can be stored in the primary storage device **104** to replace the deleted data in primary data **112** (or other source copy) and to point to or otherwise indicate the new location in a secondary storage device **108**.

According to one example, files are generally moved between higher and lower cost storage depending on how often the files are accessed. When a user requests access to the HSM data that has been removed or migrated, the information management system **100** uses the stub to locate the data and often make recovery of the data appear transparent, even though the HSM data may be stored at a location different from the remaining source data. The stub may also include some metadata associated with the corresponding data, so that a file system and/or application can provide some information about the data object and/or a limited-functionality version (e.g., a preview) of the data object.

An HSM copy may be stored in a format other than the native application format (e.g., where the data is compressed, encrypted, deduplicated, and/or otherwise modified from the original application format). In some cases, copies which involve the removal of data from source storage and the maintenance of stub or other logical reference information on source storage may be referred to generally as "on-line archive copies". On the other hand, copies which involve the removal of data from source storage without the maintenance of stub or other logical reference information on source storage may be referred to as "off-line archive copies".

Auxiliary Copy and Disaster Recovery Operations

An auxiliary copy is generally a copy operation in which a copy is created of an existing secondary copy **116**. For instance, an initial or "primary" secondary copy **116** may be generated using or otherwise be derived from primary data **112**, whereas an auxiliary copy is generated from the initial secondary copy **116**. Auxiliary copies can be used to create additional standby copies of data and may reside on different secondary storage devices **108** than initial secondary copies **116**. Thus, auxiliary copies can be used for recovery purposes if initial secondary copies **116** become unavailable. Exemplary compatible auxiliary copy techniques are described in further detail in U.S. Pat. No. 8,230,195, which is incorporated by reference herein.

The information management system **100** may also perform disaster recovery operations that make or retain disaster recovery copies, often as secondary, high-availability disk copies. The information management system **100** may create secondary disk copies and store the copies at disaster recovery locations using auxiliary copy or replication operations, such as continuous data replication technologies.

Depending on the particular data protection goals, disaster recovery locations can be remote from the client computing devices **102** and primary storage devices **104**, remote from some or all of the secondary storage devices **108**, or both.

Data Processing and Manipulation Operations

As indicated, the information management system **100** can also be configured to implement certain data manipulation operations, which according to certain embodiments are generally operations involving the processing or modification of stored data. Some data manipulation operations include content indexing operations and classification operations can be useful in leveraging the data under management to provide enhanced search and other features. Other data manipulation operations such as compression and encryption can provide data reduction and security benefits, respectively.

Data manipulation operations can be different than data movement operations in that they do not necessarily involve the copying, migration or other transfer of data (e.g., primary data **112** or secondary copies **116**) between different locations in the system. For instance, data manipulation operations may involve processing (e.g., offline processing) or modification of already stored primary data **112** and/or secondary copies **116**. However, in some embodiments data manipulation operations are performed in conjunction with data movement operations. As one example, the information management system **100** may encrypt data while performing an archive operation.

Content Indexing

In some embodiments, the information management system **100** "content indexes" data stored within the primary data **112** and/or secondary copies **116**, providing enhanced search capabilities for data discovery and other purposes. The content indexing can be used to identify files or other data objects having pre-defined content (e.g., user-defined keywords or phrases), metadata (e.g., email metadata such as "to", "from", "cc", "bcc", attachment name, received time, etc.).

The information management system **100** generally organizes and catalogues the results in a content index, which may be stored within the media agent database **152**, for example. The content index can also include the storage locations of (or pointer references to) the indexed data in the primary data **112** or secondary copies **116**, as appropriate. The results may also be stored, in the form of a content index database or otherwise, elsewhere in the information management system **100** (e.g., in the primary storage devices **104**, or in the secondary storage device **108**). Such index data provides the storage manager **140** or another component with an efficient mechanism for locating primary data **112** and/or secondary copies **116** of data objects that match particular criteria.

For instance, search criteria can be specified by a user through user interface **158** of the storage manager **140**. In some cases, the information management system **100** analyzes data and/or metadata in secondary copies **116** to create an "off-line" content index, without significantly impacting the performance of the client computing devices **102**. Depending on the embodiment, the system can also implement "on-line" content indexing, e.g., of primary data **112**. Examples of compatible content indexing techniques are provided in U.S. Pat. No. 8,170,995, which is incorporated by reference herein.

Classification Operations—Metabase

In order to help leverage the data stored in the information management system **100**, one or more components can be configured to scan data and/or associated metadata for classification purposes to populate a metabase of information. Such scanned, classified data and/or metadata may be included in a separate database and/or on a separate storage device from primary data **112** (and/or secondary copies **116**), such that metabase related operations do not significantly impact performance on other components in the information management system **100**.

In other cases, the metabase(s) may be stored along with primary data **112** and/or secondary copies **116**. Files or other data objects can be associated with user-specified identifiers (e.g., tag entries) in the media agent **144** (or other indices) to facilitate searches of stored data objects. Among a number of other benefits, the metabase can also allow efficient, automatic identification of files or other data objects to associate with secondary copy or other information management operations (e.g., in lieu of scanning an entire file system). Examples of compatible metabases and data classification operations are provided in U.S. Pat. Nos. 8,229,954 and 7,747,579, which are incorporated by reference herein.

Encryption Operations

The information management system **100** in some cases is configured to process data (e.g., files or other data objects, secondary copies **116**, etc.), according to an appropriate encryption algorithm (e.g., Blowfish, Advanced Encryption Standard [AES], Triple Data Encryption Standard [3-DES], etc.) to limit access and provide data security in the information management system **100**.

The information management system **100** in some cases encrypts the data at the client level, such that the client computing devices **102** (e.g., the data agents **142**) encrypt the data prior to forwarding the data to other components, e.g., before sending the data media agents **144** during a secondary copy operation. In such cases, the client computing device **102** may maintain or have access to an encryption key or passphrase for decrypting the data upon restore. Encryption can also occur when creating copies of secondary copies, e.g., when creating auxiliary copies. In yet further embodiments, the secondary storage devices **108** can implement built-in, high performance hardware encryption.

Management Operations

Certain embodiments leverage the integrated, ubiquitous nature of the information management system **100** to provide useful system-wide management functions. As two non-limiting examples, the information management system **100** can be configured to implement operations management and e-discovery functions.

Operations management can generally include monitoring and managing the health and performance of information management system **100** by, without limitation, performing error tracking, generating granular storage/performance metrics (e.g., job success/failure information, deduplication efficiency, etc.), generating storage modeling and costing information, and the like.

Such information can be provided to users via the user interface **158** in a single, integrated view. For instance, the integrated user interface **158** can include an option to show a "virtual view" of the system that graphically depicts the various components in the system using appropriate icons. The operations management functionality can facilitate planning and decision-making. For example, in some embodiments, a user may view the status of some or all jobs as well as the status of each component of the information management system **100**. Users may then plan and make decisions based on this data. For instance, a user may view high-level information regarding storage operations for the information management system **100**, such as job status, component status, resource status (e.g., network pathways, etc.), and other information. The user may also drill down or use other means to obtain more detailed information regarding a particular component, job, or the like.

In some cases the information management system **100** alerts a user such as a system administrator when a particular resource is unavailable or congested. For example, a particular primary storage device **104** or secondary storage device **108** might be full or require additional capacity. Or a component may be unavailable due to hardware failure, software problems, or other reasons. In response, the information management system **100** may suggest solutions to such problems when they occur (or provide a warning prior to occurrence). For example, the storage manager **140** may alert the user that a secondary storage device **108** is full or otherwise congested. The storage manager **140** may then suggest, based on job and data storage information contained in its database **146**, an alternate secondary storage device **108**.

Other types of corrective actions may include suggesting an alternate data path to a particular primary or secondary storage device **104**, **108**, or dividing data to be stored among various available primary or secondary storage devices **104**, **108** as a load balancing measure or to otherwise optimize storage or retrieval time. Such suggestions or corrective actions may be performed automatically, if desired. Further examples of some compatible operations management techniques and of interfaces providing an integrated view of an information management system are provided in U.S. Pat. No. 7,343,453, which is incorporated by reference herein. In some embodiments, the storage manager **140** implements the operations management functions described herein.

The information management system **100** can also be configured to perform system-wide e-discovery operations in some embodiments. In general, e-discovery operations provide a unified collection and search capability for data in the system, such as data stored in the secondary storage devices **108** (e.g., backups, archives, or other secondary copies **116**). For example, the information management system **100** may construct and maintain a virtual repository for data stored in the information management system **100** that is integrated across source applications **110**, different storage device types, etc. According to some embodiments, e-discovery utilizes other techniques described herein, such as data classification and/or content indexing.

Information Management Policies

As indicated previously, an information management policy **148** can include a data structure or other information source that specifies a set of parameters (e.g., criteria and rules) associated with secondary copy or other information management operations.

One type of information management policy **148** is a storage policy. According to certain embodiments, a storage policy generally comprises a logical container that defines (or includes information sufficient to determine) one or more of the following items: (1) what data will be associated with the storage policy; (2) a destination to which the data will be stored; (3) datapath information specifying how the data will be communicated to the destination; (4) the type of storage operation to be performed; and (5) retention information specifying how long the data will be retained at the destination.

Data associated with a storage policy can be logically organized into groups, which can be referred to as "sub-clients". A sub-client may represent static or dynamic associations of portions of a data volume. Sub-clients may represent mutually exclusive portions. Thus, in certain embodiments, a portion of data may be given a label and the association is stored as a static entity in an index, database or other storage location.

Sub-clients may also be used as an effective administrative scheme of organizing data according to data type, department within the enterprise, storage preferences, or the like. Depending on the configuration, sub-clients can correspond to files, folders, virtual machines, databases, etc. In one exemplary scenario, an administrator may find it preferable to separate e-mail data from financial data using two different sub-clients.

A storage policy can define where data is stored by specifying a target or destination storage device (or group of storage devices). For instance, where the secondary storage device **108** includes a group of disk libraries, the storage policy may specify a particular disk library for storing the sub-clients associated with the policy. As another example, where the secondary storage devices **108** include one or more tape libraries, the storage policy may specify a particular tape library for storing the sub-clients associated with the storage policy, and may also specify a drive pool and a tape pool defining a group of tape drives and a group of tapes, respectively, for use in storing the sub-client data.

Datapath information can also be included in the storage policy. For instance, the storage policy may specify network pathways and components to utilize when moving the data to the destination storage device(s). In some embodiments, the storage policy specifies one or more media agents **144** for conveying data (e.g., one or more sub-clients) associated with the storage policy between the source (e.g., one or more host client computing devices **102**) and destination (e.g., a particular target secondary storage device **108**).

A storage policy can also specify the type(s) of operations associated with the storage policy, such as a backup, archive, snapshot, auxiliary copy, or the like. Retention information can specify how long the data will be kept, depending on organizational needs (e.g., a number of days, months, years, etc.)

The information management policies **148** may also include one or more scheduling policies specifying when and how often to perform operations. Scheduling information may specify with what frequency (e.g., hourly, weekly, daily, event-based, etc.) or under what triggering conditions secondary copy or other information management operations will take place. Scheduling policies in some cases are associated with particular components, such as particular sub-clients, client computing device **102**, and the like. In one configuration, a separate scheduling policy is maintained for particular sub-clients on a client computing device **102**. The scheduling policy specifies that those sub-clients are to be moved to secondary storage devices **108** every hour according to storage policies associated with the respective sub-clients.

When adding a new client computing device **102**, administrators can manually configure information management policies **148** and/or other settings, e.g., via the user interface **158**. However, this can be an involved process resulting in delays, and it may be desirable to begin data protecting operations quickly.

Thus, in some embodiments, the information management system **100** automatically applies a default configuration to client computing device **102**. As one example, when a data agent(s) **142** is installed on a client computing devices **102**, the installation script may register the client computing device **102** with the storage manager **140**, which in turn applies the default configuration to the new client computing device **102**. In this manner, data protection operations can begin substantially immediately. The default configuration can include a default storage policy, for example, and can specify any appropriate information sufficient to begin data protection operations. This can include a type of data protection operation, scheduling information, a target secondary storage device **108**, data path information (e.g., a particular media agent **144**), and the like.

Other types of information management policies **148** are possible. For instance, the information management policies **148** can also include one or more audit or security policies. An audit policy is a set of preferences, rules and/or criteria that protect sensitive data in the information management system **100**. For example, an audit policy may define "sensitive objects" as files or objects that contain particular keywords (e.g. "confidential," or "privileged") and/or are associated with particular keywords (e.g., in metadata) or particular flags (e.g., in metadata identifying a document or email as personal, confidential, etc.).

An audit policy may further specify rules for handling sensitive objects. As an example, an audit policy may require that a reviewer approve the transfer of any sensitive objects to a cloud storage site, and that if approval is denied for a particular sensitive object, the sensitive object should be transferred to a local storage device **104** instead. To facilitate this approval, the audit policy may further specify how a secondary storage computing device **106** or other system component should notify a reviewer that a sensitive object is slated for transfer.

In some implementations, the information management policies **148** may include one or more provisioning policies. A provisioning policy can include a set of preferences, priorities, rules, and/or criteria that specify how clients **102** (or groups thereof) may utilize system resources, such as available storage on cloud storage and/or network bandwidth. A provisioning policy specifies, for example, data quotas for particular client computing devices **102** (e.g. a number of gigabytes that can be stored monthly, quarterly or annually). The storage manager **140** or other components may enforce the provisioning policy. For instance, the media agents **144** may enforce the policy when transferring data to secondary storage devices **108**. If a client computing device **102** exceeds a quota, a budget for the client computing device **102** (or associated department) is adjusted accordingly or an alert may trigger.

While the above types of information management policies **148** have been described as separate policies, one or more of these can be generally combined into a single information management policy **148**. For instance, a storage policy may also include or otherwise be associated with one or more scheduling, audit, or provisioning policies. Moreover, while storage policies are typically associated with moving and storing data, other policies may be associated with other types of information management operations. The following is a non-exhaustive list of items the information management policies **148** may specify:

- schedules or other timing information, e.g., specifying when and/or how often to perform information management operations;
- the type of secondary copy **116** and/or secondary copy format (e.g., snapshot, backup, archive, HSM, etc.);
- a location or a class or quality of storage for storing secondary copies **116** (e.g., one or more particular secondary storage devices **108**);
- preferences regarding whether and how to encrypt, compress, deduplicate, or otherwise modify or transform secondary copies **116**;
- which system components and/or network pathways (e.g., preferred media agents **144**) should be used to perform secondary storage operations;
- resource allocation between different computing devices or other system components used in performing information management operations (e.g., bandwidth allocation, available storage capacity, etc.);
- whether and how to synchronize or otherwise distribute files or other data objects across multiple computing devices or hosted services; and
- retention information specifying the length of time primary data **112** and/or secondary copies **116** should be retained, e.g., in a particular class or tier of storage devices, or within the information management system **100**.

Policies can additionally specify or depend on a variety of historical or current criteria that may be used to determine which rules to apply to a particular data object, system component, or information management operation, such as:

- frequency with which primary data **112** or a secondary copy **116** of a data object or metadata has been or is predicted to be used, accessed, or modified;
- time-related factors (e.g., aging information such as time since the creation or modification of a data object);
- deduplication information (e.g., hashes, data blocks, deduplication block size, deduplication efficiency or other metrics);
- an estimated or historic usage or cost associated with different components (e.g., with secondary storage devices **108**);
- the identity of users, applications **110**, client computing devices **102** and/or other computing devices that created, accessed, modified, or otherwise utilized primary data **112** or secondary copies **116**;
- a relative sensitivity (e.g., confidentiality) of a data object, e.g., as determined by its content and/or metadata;
- the current or historical storage capacity of various storage devices;
- the current or historical network capacity of network pathways connecting various components within the storage operation cell;
- access control lists or other security information; and
- the content of a particular data object (e.g., its textual content) or of metadata associated with the data object.

Exemplary Storage Policy and Secondary Storage Operations

FIG. **1**E shows a data flow data diagram depicting performance of storage operations by an embodiment of an information management system **100**, according to an exemplary data storage policy **148**A. The information management system **100** includes a storage manger **140**, a client computing device **102** having a file system data agent **142**A and an email data agent **142**B residing thereon, a primary storage device **104**, two media agents **144**A, **144**B, and two secondary storage devices **108**A, **1088**: a disk library **108**A and a tape library **1088**. As shown, the primary storage device **104** includes primary data **112**A, **1128** associated with a file system sub-client and an email sub-client, respectively.

As indicated by the dashed box, the second media agent **144**B and the tape library **1088** are "off-site", and may therefore be remotely located from the other components in the information management system **100** (e.g., in a different city, office building, etc.). In this manner, information stored on the tape library **108**B may provide protection in the event of a disaster or other failure.

The file system sub-client and its associated primary data 112A in certain embodiments generally comprise information generated by the file system and/or operating system of the client computing device 102, and can include, for example, file system data (e.g., regular files, file tables, mount points, etc.), operating system data (e.g., registries, event logs, etc.), and the like. The e-mail sub-client, on the other hand, and its associated primary data 1128, include data generated by an e-mail client application operating on the client computing device 102, and can include mailbox information, folder information, emails, attachments, associated database information, and the like. As described above, the sub-clients can be logical containers, and the data included in the corresponding primary data 112A, 1128 may or may not be stored contiguously.

The exemplary storage policy 148A includes a backup copy rule set 160, a disaster recovery copy rule set 162, and a compliance copy rule set 164. The backup copy rule set 160 specifies that it is associated with a file system sub-client 166 and an email sub-client 168. Each of these sub-clients 166, 168 are associated with the particular client computing device 102. The backup copy rule set 160 further specifies that the backup operation will be written to the disk library 108A, and designates a particular media agent 144A to convey the data to the disk library 108A. Finally, the backup copy rule set 160 specifies that backup copies created according to the rule set 160 are scheduled to be generated on an hourly basis and to be retained for 30 days. In some other embodiments, scheduling information is not included in the storage policy 148A, and is instead specified by a separate scheduling policy.

The disaster recovery copy rule set 162 is associated with the same two sub-clients 166, 168. However, the disaster recovery copy rule set 162 is associated with the tape library 108B, unlike the backup copy rule set 160. Moreover, the disaster recovery copy rule set 162 specifies that a different media agent 144B than the media agent 144A associated with the backup copy rule set 160 will be used to convey the data to the tape library 1088. As indicated, disaster recovery copies created according to the rule set 162 will be retained for 60 days, and will be generated on a daily basis. Disaster recovery copies generated according to the disaster recovery copy rule set 162 can provide protection in the event of a disaster or other data-loss event that would affect the backup copy 116A maintained on the disk library 108A.

The compliance copy rule set 164 is only associated with the email sub-client 166, and not the file system sub-client 168. Compliance copies generated according to the compliance copy rule set 164 will therefore not include primary data 112A from the file system sub-client 166. For instance, the organization may be under an obligation to store maintain copies of email data for a particular period of time (e.g., 10 years) to comply with state or federal regulations, while similar regulations do not apply to the file system data. The compliance copy rule set 164 is associated with the same tape library 108B and media agent 144B as the disaster recovery copy rule set 162, although a different storage device or media agent could be used in other embodiments. Finally, the compliance copy rule set 164 specifies that copies generated under the compliance copy rule set 164 will be retained for 10 years, and will be generated on a quarterly basis.

At step 1, the storage manager 140 initiates a backup operation according to the backup copy rule set 160. For instance, a scheduling service running on the storage manager 140 accesses scheduling information from the backup copy rule set 160 or a separate scheduling policy associated with the client computing device 102, and initiates a backup copy operation on an hourly basis. Thus, at the scheduled time slot the storage manager 140 sends instructions to the client computing device 102 to begin the backup operation.

At step 2, the file system data agent 142A and the email data agent 142B residing on the client computing device 102 respond to the instructions received from the storage manager 140 by accessing and processing the primary data 112A, 112B involved in the copy operation from the primary storage device 104. Because the operation is a backup copy operation, the data agent(s) 142A, 142B may format the data into a backup format or otherwise process the data.

At step 3, the client computing device 102 communicates the retrieved, processed data to the first media agent 144A, as directed by the storage manager 140, according to the backup copy rule set 160. In some other embodiments, the information management system 100 may implement a load-balancing, availability-based, or other appropriate algorithm to select from the available set of media agents 144A, 144B. Regardless of the manner the media agent 144A is selected, the storage manager 140 may further keep a record in the storage manager database 140 of the association between the selected media agent 144A and the client computing device 102 and/or between the selected media agent 144A and the backup copy 116A.

The target media agent 144A receives the data from the client computing device 102, and at step 4 conveys the data to the disk library 108A to create the backup copy 116A, again at the direction of the storage manager 140 and according to the backup copy rule set 160. The secondary storage device 108A can be selected in other ways. For instance, the media agent 144A may have a dedicated association with a particular secondary storage device(s), or the storage manager 140 or media agent 144A may select from a plurality of secondary storage devices, e.g., according to availability, using one of the techniques described in U.S. Pat. No. 7,246,207, which is incorporated by reference herein.

The media agent 144A can also update its index 153 to include data and/or metadata related to the backup copy 116A, such as information indicating where the backup copy 116A resides on the disk library 108A, data and metadata for cache retrieval, etc. After the 30 day retention period expires, the storage manager 140 instructs the media agent 144A to delete the backup copy 116A from the disk library 108A.

At step 5, the storage manager 140 initiates the creation of a disaster recovery copy 1168 according to the disaster recovery copy rule set 162. For instance, at step 6, based on instructions received from the storage manager 140 at step5, the specified media agent 144B retrieves the most recent backup copy 116A from the disk library 108A.

At step 7, again at the direction of the storage manager 140 and as specified in the disaster recovery copy rule set 162, the media agent 144B uses the retrieved data to create a disaster recovery copy 1168 on the tape library 1088. In some cases, the disaster recovery copy 1168 is a direct, mirror copy of the backup copy 116A, and remains in the backup format. In other embodiments, the disaster recovery copy 116C may be generated in some other manner, such as by using the primary data 112A, 1128 from the storage device 104 as source data. The disaster recovery copy operation is initiated once a day and the disaster recovery copies 116A are deleted after 60 days.

At step 8, the storage manager 140 initiates the creation of a compliance copy 116C, according to the compliance copy rule set 164. For instance, the storage manager 140 instructs the media agent **144**B to create the compliance copy **116**C on the tape library **1088** at step 9, as specified in the compliance copy rule set **164**. In the example, the compliance copy **116**C is generated using the disaster recovery copy **1168**. In other embodiments, the compliance copy **116**C is instead generated using either the primary data **1128** corresponding to the email sub-client or using the backup copy **116**A from the disk library **108**A as source data. As specified, compliance copies **116**C are created quarterly, and are deleted after ten years.

While not shown in FIG. **1**E, at some later point in time, a restore operation can be initiated involving one or more of the secondary copies **116**A, **1168**, **116**C. As one example, a user may manually initiate a restore of the backup copy **116**A by interacting with the user interface **158** of the storage manager **140**. The storage manager **140** then accesses data in its index **150** (and/or the respective storage policy **148**A) associated with the selected backup copy **116**A to identify the appropriate media agent **144**A and/or secondary storage device **116**A.

In other cases, a media agent may be selected for use in the restore operation based on a load balancing algorithm, an availability based algorithm, or other criteria. The selected media agent **144**A retrieves the data from the disk library **108**A. For instance, the media agent **144**A may access its index **153** to identify a location of the backup copy **116**A on the disk library **108**A, or may access location information residing on the disk **108**A itself.

When the backup copy **116**A was recently created or accessed, the media agent **144**A accesses a cached version of the backup copy **116**A residing in the media agent index **153**, without having to access the disk library **108**A for some or all of the data. Once it has retrieved the backup copy **116**A, the media agent **144**A communicates the data to the source client computing device **102**. Upon receipt, the file system data agent **142**A and the email data agent **142**B may unpackage (e.g., restore from a backup format to the native application format) the data in the backup copy **116**A and restore the unpackaged data to the primary storage device **104**.

Exemplary Secondary Copy Formatting

The formatting and structure of secondary copies **116** can vary, depending on the embodiment. In some cases, secondary copies **116** are formatted as a series of logical data units or "chunks" (e.g., 512 MB, 1 GB, 2 GB, 4 GB, or 8 GB chunks). This can facilitate efficient communication and writing to secondary storage devices **108**, e.g., according to resource availability. For example, a single secondary copy **116** may be written on a chunk-by-chunk basis to a single secondary storage device **108** or across multiple secondary storage devices **108**. In some cases, users can select different chunk sizes, e.g., to improve throughput to tape storage devices.

Generally, each chunk can include a header and a payload. The payload can include files (or other data units) or subsets thereof included in the chunk, whereas the chunk header generally includes metadata relating to the chunk, some or all of which may be derived from the payload. For example, during a secondary copy operation, the media agent **144**, storage manager **140**, or other component may divide the associated files into chunks and generate headers for each chunk by processing the constituent files.

The headers can include a variety of information such as file identifier(s), volume(s), offset(s), or other information associated with the payload data items, a chunk sequence number, etc. Importantly, in addition to being stored with the secondary copy **116** on the secondary storage device **108**, the chunk headers can also be stored to the index **153** of the associated media agent(s) **144** and/or the storage manager index **150**. This is useful in some cases for providing faster processing of secondary copies **116** during restores or other operations. In some cases, once a chunk is successfully transferred to a secondary storage device **108**, the secondary storage device **108** returns an indication of receipt, e.g., to the media agent **144** and/or storage manager **140**, which may update their respective indexes **150**, **153** accordingly.

During restore, chunks may be processed (e.g., by the media agent **144**) according to the information in the chunk header to reassemble the files. Additional information relating to chunks can be found in U.S. Pat. No. 8,156,086, which is incorporated by reference herein.

System Overview

The systems and methods described with respect to FIGS. **1**A-**1**E can be used for protecting secondary copy data. For instance, the system of FIG. **1**C applies backup policies and backs up data from the client computing device **102** in the data storage system **100**. In other embodiments, data storage systems include virtual computing devices or virtual machines (VM). As indicated above, virtual machines have the same support, security and compliance issues as physical machines. Systems and methods are described herein to protect virtual machines using block-level backup operations and to restore the data at a file level. Further examples of systems and methods for 1) processing blocks during virtual machine backup; 2) selecting specific virtual machine files to restore from the block-level backup using a user interface; and 3) restoring selected virtual machine files from the block-level backup are described below with respect to FIGS. **2**-**5**.

FIG. **2** is a block diagram illustrating an arrangement of resources that form an example information management system or information management cell **250**. According to certain embodiments, some or all of the components of the information management cell **250** of FIG. **2** may have the same or similar structure and/or functionality as the similarly named components of the information management cell of FIGS. **1**C and **1**D. As shown, the information management cell **250** can include virtual machine (VM) management software or hypervisor **240**, one or more virtual machines (VM) **285**, one or more primary data storage devices, data stores, or information stores **290**, storage manager or information manager **201**, one or more media agents **205**, and one or more secondary storage devices **215**.

The storage manager or information manager **201** may be a software module or other application that coordinates and/or controls storage operations performed by one or more information management cells **250**, similar to that described above for the storage or information manager **140** and the information management cell **100** of FIG. **1**C. In this manner, the storage manager or information manager **201** may act as a generally central control component with respect to the other components in the information management cell **250**. As shown by the dashed lines, the storage manager or information manager **201** may communicate with and/or control some or all elements of the information management cell **250**, such as the media agents **205** and virtual machines **285**, to initiate, coordinate, and/or manage secondary copy operations.

The storage manager or information manager **201** comprises a virtual machine (VM) data protection module **210** which, when executed, interfaces with one or more of the data agent **295**, the media agent **205**, the VM management software **240**, and the host operating system to determine which blocks relate to which files when performing a block-based backup of the virtual machine **285**. This information is then stored as a file index in association with the block-based backup. Moreover, as will be described below, the VM data protection module **210**, when executed, can access the file index associated with the block-level backup and interface with a graphical user interface (GUI) to display the list of files to the user. Upon selection of a particular file, the VM data protection module **210**, when executed, uses the file index to identify the blocks associated with the selected file. The identified blocks are restored, combined to create the file, and presented to the user.

While the VM data protection module **210** is shown as residing on the storage manager **201**, in some embodiments, virtual machine backup and file restore functionality is advantageously distributed among other components in the system. For instance, depending on the embodiment, rule agents can execute on or form a part of one or more of the virtual machines **285**, one or more of the data agents **295**, or one or more of the media agents **205**.

As described above with respect to storage or information manager **140** of FIG. **1**C, the storage manager or information manager **201** may maintain a management database **260** of management-related data and policies. As shown, the management database **260** may include a management index **252** or other data structure that stores logical associations between components of the system, user preferences and/or profiles, such as preferences regarding the scheduling, type, or other aspects of secondary copy operations, management tasks, media containerization, or other useful data.

The management database **260** may maintain various information management policies **248** and associated data, which in some embodiments are stored in the management database **260** of the storage manager **201**, although the information management policies **248** can be stored in any appropriate location. A storage or other information management policy **248** may be stored in a media agent database **226** or in a secondary storage device **215** (e.g., as an archive copy) as metadata for use in information management operations, depending on the embodiment.

Generally, an information management policy **248** can include a data structure or other information source that specifies a set of parameters (e.g., criteria and rules) associated with performing one or more information management operations. With respect to secondary copy operations (e.g. data backup operations), in some embodiments, an information management policy **248** can be a data structure that defines at least timing information, the type(s) of secondary copy operations, and information sufficient to determine a secondary storage destination (e.g., a location or class or quality of storage media) for storing the secondary copy. In an embodiment, one or more information management policies **248** may be associated with the VM data protection module **210**, such that the VM data protection module **210** is executed in conjunction with the associated storage policy **248**.

Similar to the media agents **144** described above, media agents **205** may be implemented as a software module that manages, coordinates, and facilitates the transmission of data, as directed by the storage manager **201**, between the virtual machine **285** and one or more secondary storage devices **215**. Whereas the storage manager **201** controls the operation of the information management cell **250**, the media agent **205** generally provides a portal to secondary storage devices **215**.

A media agent **205** (and corresponding media agent database **226**) may be considered to be "associated with" a particular secondary storage device **215** if that media agent **205** is capable of one or more of: routing and/or storing data to the particular secondary storage device **215**, coordinating the routing and/or storing of data to the particular secondary storage device **215**, retrieving data from the particular secondary storage device **215**, and coordinating the retrieval of data from a particular secondary storage device **215**.

As shown, each media agent **205** may maintain an associated media agent database **226**. The media agent database **226** can include, among other things, a media agent index **253** including data generated during secondary copy operations and other storage or information management operations. The media agent index **253** provides a media agent **205** or other component with a fast and efficient mechanism for locating secondary copies or other data stored in the secondary storage devices **215**. In one configuration, a management index **252** or other data structure may store data associating a virtual machine **285** with a particular media agent **205** and/or secondary storage device **215**, as specified in a storage policy. A media agent index **253** or other data structure associated with the particular media agent **205** may in turn include information about the stored data.

For instance, for each secondary copy, the media agent index **253** may include a path to the secondary copy on the corresponding secondary storage device **215**, location information indicating where the data objects are stored in the secondary storage device **215**, when the data objects were created or modified, etc. Thus, the media agent index **253** includes metadata associated with the secondary copies that is readily available for use in storage operations and other activities without having to be first retrieved from the secondary storage device **215**.

The VM management software or hypervisor **240**, in an embodiment, configures, provisions, and manages virtualized environments, and stores information about the physical servers, resource pools, and virtual machines **285**. Examples of VM management software **740** are Oracle® VM Server for SPARC, Citrix® XenServer, Kernel-based Virtual Machine (KVM) for a Linux® kernel, VMware® ESX/ESXi, VMware® Workstation, Microsoft® Hyper-V hypervisor, and the like. As shown, there may be multiple instances of virtual machine management software **240**, each managing a separate group of one or more virtual machines **285**. Each instance of virtual machine management software **240** may reside on a separate physical host computing device.

The virtual machine **285** is a software implementation of a computing environment in which an operating system or program can be installed and run. This operating system is often known as the guest operating system. The virtual machine **285** typically emulates a physical computing environment, but requests for CPU, memory, hard disk, network and other hardware resources are managed by a virtualization layer which translates these requests to the underlying physical hardware. This underlying physical hardware is often known as the host.

The virtual machines **285** are created within the virtualization layer, such as the virtual machine management software or hypervisor **240** that runs on top of a client or server operating system. This operating system is often known as the host operating system. The virtual machine management software or hypervisor **240** can be used to create many individual, isolated virtual machine environments.

Typically, guest operating systems and programs are not aware that they are running on a virtual platform and, as long as the virtual machine's virtual platform is supported, this software can be installed in the same way it would be deployed to physical server hardware. For example, the guest operating system might appear to have a physical hard disk attached to it, but actual I/O requests are translated by the virtualization layer so they actually occur against a file that is accessible by the host operating system.

The host operating system runs on the physical hardware or host underlying the virtualization layer. Examples of host operating systems are Unix®, Linux®, Windows®, and the like. Typically, the file allocation system of the host operating system uses a file allocation table (FAT) to keep track of the physical or logical clusters across which each file in the information store **290** is stored. Clusters are small blocks of contiguous space on the information store **290**. Each file may occupy one or more clusters. Thus, a file is represented by a chain of these clusters. However, the clusters representing a file are not necessarily stored adjacent to one another in the information store **290**, but are often fragmented throughout the data region. In an embodiment, the FAT comprises a list, table, or index of the files and for each file, a linked list of the clusters representing the file.

The virtual machines **285** comprise data agents **295**. Similar to the function of data agents **142** described above, each data agent **295** may be configured to access data and/or metadata stored in the primary storage device(s) **290** associated with the data agent **295** and process the data as appropriate. For example, during a secondary copy operation, the data agent **295** may arrange or assemble the data and metadata into one or more files having a certain format (e.g., a particular backup or archive format) before transferring the file(s) to a media agent **205** or other component. Each data agent **295** can also assist in restoring data or metadata to primary storage devices **290** from a secondary copy. For instance, the data agent **295** may operate in conjunction with the storage manager **201** and one or more of the media agents **205** to restore data from secondary storage device(s) **215**.

By executing the VM data protection module **210** during a data protection operation, such as backup, the storage manager or information manager **201** instructs the media agent **205** to attach or mount onto the host operating system underlying the virtual machine **285** to be protected. In another embodiment, the information or storage manager **201** instructs the host operating system to mount the media agent **205**. Thus, the media agent **205** can access the file related information or metadata in the FAT of the host operating system. Further, the storage manager or information manager **201** instructs the media agent **205** to perform a block-level backup of the virtual machine **285**, and create a file index by determining which blocks relate to which files based at least in part on the file information stored in the FAT of the host operating system. In an embodiment, the file index is associated with the media agent index **253**. In another embodiment, the file index is incorporated into the media agent index **253**.

In an embodiment, the file index can be obtained by an agent residing on the virtual machine **285** which monitors file creation, deletion, and renames.

In another embodiment, the block level backup data can be used to construct the file index when the user requests the list of files. By exposing the block level backup as a virtual device to a virtual machine, the guest operating system reads the file server to obtain the file level data (i.e. the file lists). The file level index is implicitly contained in the block level backup data.

By executing the VM data protection module during a user initiated instruction to perform a file restore, the storage manager **201** instructs the media agent to **205** to display a list of the files based at least in part on the file index and/or the media agent index **253**. After selection of the file from the displayed list of files, the storage manager **201** instructs the media agent **205** to identify the blocks associated with the selected file, restore the identified blocks, recreate the selected file, and present the restored file to the user.

With further reference to FIG. **2**, the interaction between the various components of the example information management cell **250** will now be described in greater detail.

FIG. **3** illustrates a flow chart of an exemplary embodiment of a process **300** usable by the information management cell **250** of FIG. **2** to perform a block-level backup with file-level restore granularity for virtual machines **285**. Beginning at step **302**, the process **300** queries the media agent **205** for the address of the VM disk associated with the virtual machine **285** to be protected. In an embodiment, the storage manager **201** queries the media agent **205** and the media agent **205** looks up the address of the virtual machine disk using the media agent index **253**. At step **304**, the process **300** receives the address of the virtual machine disk from the media agent **205**.

At step **306**, the process **300** mounts or attaches the media agent **205** onto the host operating system. In an embodiment, mounting the media agent **205** onto the host operating system creates a new virtual machine **285** comprising the media agent **205** in the virtual machine management software **240**. As described above, the FAT of the host operating system keeps track of the physical or logical clusters across which each file in the information store **290** is stored. When the media agent **205** is mounted to the host operating system, the media agent **205** has access to file system of the host operating system, including the FAT comprising file information or metadata.

At step **308**, the process **300** performs a block-level backup of the virtual machine **285**. In an embodiment, under the direction of the storage manager **201**, blocks of data are transmitted from the primary storage device **290** to the secondary storage device **215**. As described above, the data agent **295** facilitates the data transfer from the primary storage device **290** to or through the media agent **205** and the media agent **205** facilitates the transfer of the data from or through the data agent **295** to the secondary storage device **215**.

Further details of step **308** are described with respect to steps **3081-3083**. At step **3081**, the block of data is copied from the primary storages device **290** and transferred to the secondary storage device **215**.

At step **3082**, the media agent **205** updates the media agent index **253** with the storage location in the secondary storage device **215** of the transferred data block. In an embodiment, the media agent index **253** comprises an index that associates the location in primary data storage **290** of the block to the location of the corresponding transferred block in secondary storage device **215**. In another embodiment, the block-level backup is an incremental backup such that only new or changed blocks since the previous backup are transferred to the secondary storage device **215**. In that case, the media agent **205** updates the media agent index **253** with the location of the new or changed blocks such that the media agent index **253** comprises a linked list of blocks, block addresses and/or block lengths that can be used to restore the blocks as they appeared in the primary storage device **290**.

At step **3083**, the media agent **205** associates the block with its related file in the media agent index **253**. As described above, the FAT comprises a listing of the files and their storage location in the primary storage device **290**. The media agent **205** retrieves the file information from the FAT of the host operating system and adds the file information in the media agent index **253**. Steps **3081-3083** repeat for each block in the block-level backup of the virtual machine **285**.

In one embodiment, the media agent index **253** comprises a table configured to associate the files and/or versions of the files with the linked data blocks for each file. The media agent index **253** can then be used to restore a specific file and/or file version.

FIG. **4** illustrates a flow chart of an exemplary embodiment of a process **400** usable by the information management cell **250** of FIG. **2** to select specific virtual machine restore files from the block-level backup. At step **402**, the information management cell **250** receives a user instruction to perform a file restore. At step **404**, the process **400** instructs the media agent **205** to read the media agent index **253** comprising an association of the block locations from the block-level backup of the virtual machine **285** with the file information from the FAT for the virtual files of the virtual machine **285**.

At step **406**, the process **400** creates a file level table based at least in part on the file information stored in the media agent index **253**, and at step **408**, the process **400** displays the listing of files to the user. In an embodiment, the files are displayed on a graphical user interface (GUI). In one embodiment, the file names are displayed on the GUI. In another embodiment, the files and each protected version of the file along with the date of the protected file version is displayed on the GUI.

At step **410**, the storage manager **201** receives the user selected file to restore.

FIG. **5** illustrates a flow chart of an exemplary embodiment of a process **500** usable by the information management system **250** of FIG. **2** to restore a selected virtual machine file from a block-level backup without restoring blocks associated with files other than the selected virtual machine file. At step **502**, the process **500** identifies the one or more blocks associated with the selected file and/or file version in the media agent index **253**. In an embodiment, the storage manager **201** instructs the media agent **205** to identify the one or more blocks associated with the selected file and/or selected file version in the media agent index **253**. In another embodiment, the media agent **205** identifies only the one or more blocks associated with the selected file and/or the selected file version in the media agent index **253**.

At step **504**, the process **500** restores the identified blocks without restoring blocks associated with files other than the selected file and/or file version. At step **506**, the process recreates the selected file from the restored blocks and at step **508**, the restored file is presented to the user. In an embodiment, the restored file is displayed on the GUI.

Thus, in an embodiment, the media agent **205** accesses the VM file information from the FAT and associates this VM file information with the related protected blocks in the secondary storage device **215** during the block-level backup. The media agent **205** using the media agent index **253** can identify the specific blocks in the secondary storage device **215** associated with the selected restore file. As a result, file level granularity for restore operations is possible for virtual machine data protected by block-level backup operations without restoring more than the selected file blocks from the block-level backup data. In another embodiment, the information management cell **250** is able to associate blocks with their files during a block-level backup of a virtual machine **285** and then restore with file level granularity using the block-level backup data.

Terminology

Conditional language, such as, among others, "can," "could," "might," or "may," unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or steps. Thus, such conditional language is not generally intended to imply that features, elements and/or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without user input or prompting, whether these features, elements and/or steps are included or are to be performed in any particular embodiment.

Depending on the embodiment, certain acts, events, or functions of any of the algorithms described herein can be performed in a different sequence, can be added, merged, or left out all together (e.g., not all described acts or events are necessary for the practice of the algorithms). Moreover, in certain embodiments, acts or events can be performed concurrently, e.g., through multi-threaded processing, interrupt processing, or multiple processors or processor cores or on other parallel architectures, rather than sequentially.

Systems and modules described herein may comprise software, firmware, hardware, or any combination(s) of software, firmware, or hardware suitable for the purposes described herein. Software and other modules may reside on servers, workstations, personal computers, computerized tablets, PDAs, and other devices suitable for the purposes described herein. Software and other modules may be accessible via local memory, via a network, via a browser, or via other means suitable for the purposes described herein. Data structures described herein may comprise computer files, variables, programming arrays, programming structures, or any electronic information storage schemes or methods, or any combinations thereof, suitable for the purposes described herein. User interface elements described herein may comprise elements from graphical user interfaces, command line interfaces, and other suitable interfaces.

Further, the processing of the various components of the illustrated systems can be distributed across multiple machines, networks, and other computing resources. In addition, two or more components of a system can be combined into fewer components. Various components of the illustrated systems can be implemented in one or more virtual machines, rather than in dedicated computer hardware systems. Likewise, the data repositories shown can represent physical and/or logical data storage, including, for example, storage area networks or other distributed storage systems. Moreover, in some embodiments the connections between the components shown represent possible paths of data flow, rather than actual connections between hardware. While some examples of possible connections are shown, any of the subset of the components shown can communicate with any other subset of components in various implementations.

Embodiments are also described above with reference to flow chart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products. Each block of the flow chart illustrations and/or block diagrams, and combinations of blocks in the flow chart illustrations and/or block diagrams, may be implemented by computer program instructions. Such instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the acts specified in the flow chart and/or block diagram block or blocks.

These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to operate in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instruction means which implement the acts specified in the flow chart and/or block diagram block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operations to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the acts specified in the flow chart and/or block diagram block or blocks.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure. Indeed, the novel methods and systems described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the described methods and systems may be made without departing from the spirit of the disclosure.

What is claimed is:

1. A method to restore a selected file from block-level data protection of virtual machine files without restoring blocks of data associated with other than the selected file in a data management system, the method comprising:

receiving, with a storage manager in a first computing device comprising computer hardware, an indication of a selected virtual file to restore from a file level table of virtual files associated with a virtual machine backed up by a block-level data protection operation, wherein the virtual machine is associated with a media agent and a host operating system of a host computing device having a file allocation table (FAT) comprising file information of the virtual files in an information store associated with the virtual machine;

using, with the media agent, a file index to locate transferred blocks of data in a secondary storage device that comprise at least a portion of the selected virtual file, the file index comprising file information for blocks of data transferred from the virtual machine to the secondary storage device during the block-level data protection operation, the file information comprising a location of the selected virtual file within the information store and obtained from the FAT of the host operating system during the block-level data protection operation;

automatically restoring, with the media agent, one or more transferred blocks of data in the secondary storage device that are associated with the at least the portion of the selected virtual file without restoring transferred blocks of data associated with other than the selected virtual file to create restored blocks of data;

using the file index to locate the at least the portion of the selected virtual file in the restored one or more blocks of data, automatically recreating, with the media agent, the selected virtual file from the restored one or more blocks of data to create a recreated file; and

automatically presenting, with the storage manager, the recreated file on a graphical user interface (GUI).

2. The method of claim 1 wherein the file information comprises, for each virtual file, a linked list of one or more clusters across which the virtual file is stored on the information store.

3. The method of claim 1 wherein the file information comprises metadata.

4. The method of claim 1 further comprising instructing, with the storage manager, the media agent to identify, in the file index, the one or more blocks of data in the secondary storage device associated with the selected virtual file.

5. The method of claim 1 wherein the file level table comprises names of the virtual files and the indication comprises the name of the selected virtual file.

6. The method of claim 1 wherein the file level table comprises a listing of protected versions of each virtual file and a date of each protected version, and the indication comprises the date of the protected version of the selected virtual file.

7. The method of claim 1 wherein the media agent comprises a media agent index, and the file index is associated with the media agent index.

8. The method of claim 1 wherein the media agent comprises a media agent index which incorporates the file index.

9. A system to restore a selected file from block-level data protection of virtual files without restoring blocks of data associated with other than the selected file in a data management system, the system comprising:

a storage manager in a first computing device comprising computer hardware configured to receive an indication of a selected virtual file to restore from a file level table of virtual files associated with a virtual machine backed up by a block-level data protection operation, wherein the virtual machine is associated with a media agent and a host operating system of a host computing device having a file allocation table (FAT) comprising file information of the virtual files in an information store associated with the virtual machine;

the media agent configured to use a file index to locate transferred blocks of data in the secondary storage device that comprise at least a portion of the selected virtual file, the file index comprising file information for blocks of data transferred from the virtual machine to a secondary storage device during the block-level data protection operation, the file information comprising a location of the selected virtual file within the information store and obtained from the FAT during the block-level data protection operation;

the media agent further configured to automatically restore one or more transferred blocks of data in the secondary storage device that are associated with the at least the portion of the selected virtual file without restoring transferred blocks of data associated with other than the selected virtual file to create restored blocks of data,

the media agent, using the file index to locate the at least the portion of the selected virtual file in the restored one or more blocks of data, further configured to automatically recreate the selected virtual file from the restored one or more blocks of data to create a recreated file; and

the storage manager further configured to automatically present the recreated file on a graphical user interface (GUI).

10. The system of claim 9 wherein the file information comprises, for each virtual file, a linked list of one or more clusters across which the virtual file is stored on the information store.

11. The system of claim **9** wherein the file information comprises metadata.

12. The system of claim **9** wherein the storage manager instructs the media agent to identify, in the file index, the one or more blocks of data in the secondary storage device associated with the selected virtual file.

13. The system of claim **9** wherein the file level table comprises names of the virtual files and the indication comprises the name of the selected virtual file.

14. The system of claim **9** wherein the file level table comprises a listing of protected versions of each virtual file and a date of each protected version, and the indication comprises the date of the protected version of the selected virtual file.

15. The system of claim **9** wherein the media agent comprises a media agent index, and the file index is associated with the media agent index.

16. The system of claim **9** wherein the media agent comprises a media agent index which incorporates the file index.

* * * * *